TRANSACTIONS

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

VOLUME 26

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OF

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

No. 539

THE TWENTY-SIXTH ANNUAL MEETING 1920

THE Twenty-sixth Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS which was held at New York, N. Y., in the United Engineering Societies Building on January 27, 28, and 29, 1920, surpassed all precedent. No greater proof can be given than the large registration and the alert, attentive gatherings that heard and discussed the papers read at the sessions. The discussions brought out many healthy differences of opinion that showed growth in the individual members and served as a stimulus to the Society for further research which should determine the facts on subjects heretofore more or less theoretically regarded. Thus the Meeting fulfilled two ends: It recorded the results of a year of well spent effort on the part of individual members and the Society as a whole, and it suggested the lines upon which work for another year might well proceed to advance the profession of heating and ventilating.

An indication of the attention awakened by the work of the Society is the fact that the number of Journals distributed in advance of this Annual Meeting of 1920, exceeded by over 1,000, the number required for the Meeting of 1919. The interest evidenced in the professional sessions has been unprecedented throughout.

The opening session of the Meeting was the usual business session, devoted to addresses from the President and reports from various Officers and Committees of the Society. The total registration at the Meeting was 314; of these, 163 were Members and 151 guests.

Of general interest were the professional sessions devoted to the various topics and problems of the heating and ventilating engineer. The second session was devoted to an address on Industrial Relations and to the most promising activity of the Society, the Research Department. The third session included questions of ventilation and

drying. The fourth session of the Meeting was devoted to the subject of heating boilers and the fifth was given over to the topic of fuel. The sixth or last session concluded the Meeting with professional papers on various topics of interest. The list of subjects covered a wide range and represented practically every branch of the field of heating and ventilating engineering. Extended discussions accompanied the presentation of the papers which will prove of great assistance to the profession at large.

The papers presented at the Meeting are shown in the following program. Following this, is the report of the Committee on Research and thereafter the technical papers and discussions in the order of their presentation at the Meeting.

PROGRAM

FIRST SESSION

Tuesday, January 27, 2 P. M.

Business Session:

Announcement of Quorum.
Appointment of Tellers of Annual Election.
Address of President.
Report of the Secretary.
Report of the Council.
Report of the Treasurer.
Reports of Committees:
  Committee on Revision of Constitution.
  Committee on Automatic Ventilators.
  Committee on Furnace Heating.
  Committee to Confer with Weather Bureau.
Unfinished Business.
Report of Tellers of Annual Election.
New Business.

SECOND SESSION

Tuesday, January 27, 8 P. M.

Industrial Relations:

Address:
  The Co-operative Movement, by James P. Warbasse, President—Co-operative League of America.

Research Session:

Paper:
  Heat Losses from Direct Radiation, by John R. Allen.
Paper:
  Progress Report of the Committee on Research.
Paper:
  Tests to Determine the Efficiency of Coal Stoves, by John R. Allen and F. B. Rowley.
Paper:
  A Report of Progress in Warm Air Furnace Testing at the University of Illinois, by A. C. Willard.
Paper:
  Determination of Radiant Heat Given Off by a Direct Radiator, by John R. Allen and F. B. Rowley.

THIRD SESSION

Wednesday, January 28, 2 P. M.

Ventilation Session:

Paper:

An Advance in Air Conditioning in School Buildings, by E. S. Hallett.

Paper:

Test of the Beery System of Heating and Ventilating, by C. E. Beery.

Report:

Status of School Ventilation in the United States.

Drying Session:

Paper:

Recent Developments in Drying, by C. E. Mangels.

Address:

Dehydration, by Dr. R. H. McKee.

FOURTH SESSION

Wednesday, January 28, 8 P. M.

Heating Boiler Session:

Paper:

The Magazine Feed Boiler and Fuel Conservation, by Chas. F. Newport.

Address by E. C. Molby on Development of Magazine Feed Boiler.

Paper:

Relation of Boiler Heating Surface Area to Boiler Capacity, by P. J. Dougherty.

Paper:

Four Years Experience in Prevention of Corrosion of Pipe, by F. N. Speller and W. H. Walker.

FIFTH SESSION

Thursday, January 29, 10 A. M.

Fuel Session:

Paper:

Oil as a Fuel for Boilers and Furnaces, by H. H. Fleming.

Paper:

Oil Fuel, by F. W. Staley.

Paper:

Fuel Oil Equipment, by John P. Leask.

Paper:

Oil Fuel versus Coal, by David Moffat Myers.

Address:

Oil Fuel, by W. C. McTarnahan.

Paper:

PULVERIZED FUEL—BY E. R. KNOWLES

SIXTH SESSION

Thursday, January 29, 2 P. M.

Professional Session:

Paper:

Work of the Construction Division of the War Department, by Major R. W. Alger.

Paper:

Atmospheric Heating System for Railroad Cars, by Thos. H. Ireland.

Paper:

Color Schemes for Distinguishing Plant Piping, by H. L. Wilkinson.

Topical Discussion:

Ventilation of Garages.

REPORT OF COMMITTEE ON RESEARCH

We beg to submit a report of the activities of this Committee and the Bureau since the Semi-Annual Meeting at Pittsburgh, Pa., June, 1919, as a full report was then submitted of the work that had been accomplished up until that time.

Finances: Director Allen commenced his duties with the Bureau on August 1st, 1919, and the Committee feels that the Bureau's fiscal year should end on July 31st, 1920. It is our intention that the budget for each year's activities shall not exceed the total amount subscribed and paid in at the time of the Annual Meeting. In other words, our collections will be made six months prior to the final expending of the money in the budget. This will give us a chance, in case the collections do not meet our expectations, to revise our budget so as to come within the funds available.

For the year 1920, there were 410 subscriptions, totaling $20,-152.50. This includes the subscription of the Armstrong Cork & Insulation Co. for material and work in insulating a cold temperature room at the Bureau of Mines, which will amount to approximately $1,500, and in order to have their name on our list continuously we have included this subscription as $300 each year for five years, although it is being paid in full at this time.

The total subscriptions unpaid for 1919 amount to $1,662, but of this amount there are $1,250 which we will undoubtedly receive from the National Boiler & Radiator Manufacturers' Association, as they are paying their subscription in quarterly payments, and the $300 which we will credit to the Armstrong Cork & Insulation Co. on their donation, as stated, leaving net unpaid subscriptions of $112, or practically ½ of 1 per cent, and we haven't given up hopes of receiving that $112.

It must be borne in mind that all the subscriptions made for 1919 were not on a five-year basis. A good many have subscribed only on a basis of one year, but we believe that the majority of those who subscribed on the basis of one year will continue to subscribe towards the support of the Bureau.

The subscriptions received on the five-year basis amounted to $12,-028.50 per year. We have subscriptions on a four-year basis which begin in 1920, of $1,927, making a total of $13,945.50, which have been subscribed for the year of 1920.

It is not our intention to send out invoices for the subscriptions for 1920 before July, as we will begin to spend this money on August 1, 1920.

We should make an effort to get additional subscriptions that will raise our fund on the five-year basis to $25,000 per year, and with the Bureau of Mines spending between $25,000 and $30,000 per year, quite a lot of work will undoubtedly be accomplished.

We recommend that a drive be instituted on March 1st and consummated on June 1st to raise the additional funds necessary to insure a $25,000 annual income, and that the bills be sent to the subscribers on June 1st of each year. I am inclined to believe that we will have no trouble in raising this money in view of the splendid showing the Bureau has made up to date. We sincerely hope that every Chapter and every member will feel sufficient interest in this work to enter upon this drive wholeheartedly to make it a success.

The total disbursements to January 1st, 1920, are $3,191.98, and our total budget provided by the Research Executive Committee amounted to $20,000. There is no question that we will come within our budget and as the budget is covered by the collections to date, we are on a firm financial basis.

As to the activities of the Director and the Bureau, we are attaching hereto the report of the Director under date of January 13, 1920, which covers this matter very fully, and all of which has been approved by the Research Committee.

In closing, this Committee wishes to congratulate the Society upon the formation of this Bureau, and upon the activities of the Director. The hardest part of work of this kind is procuring the organization, and now that Director Allen has his work fairly well organized, we are sure that the results forthcoming will be pleasing to everyone.

Chairman Lyle offered his resignation as Chairman of the Committee on Research, giving several reasons for his decision. After much debate a motion was made by Mr. Addams that the resignation of Chairman Lyle be accepted to take effect January 28, 1920, on condition that he accept the honorary chairmanship to the Committee, and that Mr. F. R. Still be made Chairman in his stead; the motion was seconded by Mr. Timmis and carried.

Respectfully submitted,

COMMITTEE ON RESEARCH,

By J. I. LYLE, *Chairman.*

REPORT OF DIRECTOR

TO THE COMMITTEE ON RESEARCH:

I take pleasure herewith in submitting my report of the work of the Research Bureau from August 1, 1919, to January 1, 1920.

Location. The Research Bureau was officially started on August 1, 1919. Shortly after that date the Director arrived in Pittsburgh and located offices in the Bureau of Mines Building, 4800 Forbes Street. The Bureau is now installed in rooms 279, 281, and 283. Through the kindness of the Bureau of Mines, the offices have been furnished with but very little expense to the Research Bureau. These rooms are well suited for the purpose and are in every way satisfactory. The Bureau has also secured a room in the basement

of the building for a constant temperature room. This room is without outside windows and has adjoining it, a room in which all of the necessary apparatus for a constant temperature room can be located.

Personnel. The office force now consists of Mr. O. W. Armspach who has been put in charge of the work on ventilation; Miss Elinor E. Mellon, secretary and stenographer, who is in charge of all the office equipment, keeping of accounts, office supplies, etc.; and Mr. Louis Ebin, who is at present, draftsman and computor for the office. Mr. Armspach and Miss Mellon are paid by the Reseach Bureau and Mr. Ebin is paid by the Bureau of Mines. It is the expectation to enlarge the staff by one or two men to be paid by the Bureau of Mines. These men will be added as soon as instruments and equipment are available to keep them supplied with work, and when the right men can be secured for the positions.

Equipment. Through the kindness of the Taylor Instrument Company, the Bureau has received a fine equipment of thermometers, both mercurial and recording, and a complete equipment of psychrometers, including one self-recording psychrometer. There is now being made by the Eimer and Amend Company, a Peterson and Palmquist gas analysis machine for determination of CO_2 in air for uses in determining infiltration and in ventilating work. The American Blower Company has very kindly donated for the use of the Bureau, a pitot tube.

The Bureau of Mines is constructing a Wahlen gauge for determining small variations of air pressure, for the use of this Bureau. In order to carry on the tests requiring uniform temperature, the Bureau is building a constant temperature room in which uniform temperatures as low as 0 deg. can be maintained at all times. The Armstrong Cork Company has very kindly offered to donate the material and the labor necessary to line this room with cork and we expect to start this very shortly. We find that in order to carry on much of our work both in heating and ventilation, a room of this kind is absolutely essential. The details of this room construction will be presented to the Society at a later date.

Inspection of Research Laboratories. The Director has spent considerable time in visiting the research laboratories of the various universities and public institutions. Among the institutions visited are the Universities of Minnesota, Wisconsin, Illinois, Michigan, Purdue, Carnegie Institute of Technology, Pittsburgh, Cornell, Penn State, Lehigh, and Pennsylvania. In general, it may be said that the universities are doing very little reseach work in heating and ventilating, especially this year when most institutions are much disturbed from their war activities and in many cases, owing to lack of funds. There is, however, some interesting work being done at the Universities of Illinois and Minnesota, and at Pennsylvania State College. Later on in the year the Director expects to visit more of the principal eastern universities.

A trip has also been made to the Bureau of Standards, Washington, D. C., to discuss certain methods of determining heat losses.

Visits to Local Chapters. The director has had the great pleasure of attending and speaking at the meetings of a number of the Chapters of the Society. He has visited the Chapters at Cleveland, Detroit, Minneapolis, New York, Pittsburgh, and Philadelphia. These visits have given him the opportunity of talking to the members and obtaining the ideas and desires of the different sections of the country in regard to the work of the Bureau, and in many cases he received valuable advice as to the methods of procedure.

Index of Information. The Bureau has a card index of about 1,000 cards dealing with various phases of research work that have been done in connection with heating and ventilating problems. It expects to make this index as complete as possible, covering all subjects bearing on research work in which it may be interested. It is hoped by the Bureau that members of the Society will make use of this index. Any members desiring information along heating and ventilating lines, particularly with reference to research can obtain a bibliography of the subject by inquiring for this information from the Bureau.

Standards. One of the functions of the Bureau is to approve standards and to determine new standards for the use of the Society. At the request of your Committee the Bureau has examined the standards already adopted by the Society. The following standards previously adopted by the Society are endorsed by the Bureau:

Report of special committee on standards for Flanged Fittings and Flanges, printed in the Transactions, Vol. XVIII, 1912, page 44. This report adopts the standards of the A. S. M. E.

Report of the Committee on the Use of the Pitot Tube, printed in the Transactions. Vol. XX, 1914, page 210.

Report of the Committee on Code for Testing Heating Boilers as revised in 1919. This report may be improved by a statement in the tables of results which shows after each result, the method of computation, similar to the statement made in the A. S. M. E. standard code for testing boilers.

Research Work at the Bureau. The Bureau has not as yet been able to do any research work in its own laboratories of extensive character. It has not been in existence long enough to build up the necessary apparatus and instruments to conduct any extensive series of tests. The instruments are now beginning to arrive and we have started work on some special apparatus. Apparatus are now being designed for the testing of radiators, for the determining of heat losses from building materials, and for determining the infiltration of air through windows. The Bureau of Mines is also carrying on experiments in the use of coke and other fuels in house-heating boilers.

Research Work Outside the Bureau. After having inspected work that is being done at the various institutions it was decided that there was only one case in which it seemed desirable for the Committee to encourage the work by financial assistance. This is the work being done at the University of Minnesota on radiant heat losses from direct radiators. Your Committee voted an appropriation of $300 for the ensuing year to be contributed toward the expenses of this work.

One of the most interesting developments in this work is the development of *a satisfactory method for measuring air at low velocities* at the University of Illinois. As this work, however, is being separately financed by other interests it did not seem necessary for us to lend financial assistance.

The Carnegie Institute of Technology is now doing some work for the Bureau in its Department of Physics. This work is being done on the *radiant heat losses* from different radiator coatings and is closely associated with the work on radiant heat losses being done at the University of Minnesota. The Carnegie Institute has very kindly agreed to finance this work itself.

Articles. The Bureau, at the Annual Meeting, will present three articles, one by the Director on Heat Losses from Direct Radiators. This particular article represents the cumulative experience of the Director covering a good many years of testing of direct radiators, and its compilation was only made possible by the fact that the Director had the undivided time to study the various tests previously made. The Bureau is also presenting two other articles in connection with Professor Rowley of the University of Minnesota, one on the Testing of Stoves, and the other on the Radiant Heat Losses from Direct Radiators.

Finances. The following report in Appendix II is a statement of the finances of the Bureau which includes a statement of the amount expended under each item of the budget.

Summary. The Director feels that the work of the Bureau is now well started and he is beginning to see the possibilities of the Bureau of Research. The more the field of research is studied along the lines of heating and ventilation, the more we realize the opportunity and necessity of obtaining exact information. It is the belief of those interested that the future will demonstrate the great wisdom of the Society in establishing this Bureau and the results obtained will be fully up to the expectations of the Society.

Respectfully submitted,

JOHN R. ALLEN, *Director,*
A. S. H. & V. E. RESEARCH BUREAU.

APPENDIX II

CASH ACCOUNT, A. S. H. & V. E. RESEARCH BUREAU

JANUARY 1, 1920

Cash Received, 1919:

August 28	$1,000.00
September 17	601.66
September 30	215.24
October 15	812.85
October 31	186.10
November 12	265.88
November 17	366.62
November 29	134.58
December 18	275.00
December 30	55.57
Total	$3,913.50

Disbursements:

Salaries, $3,646 — $1,500 from New York	2,146.00
Office Supplies and Expense	212.51
Traveling Expenses	252.87
Supplies for Heat Investigation	35.50
Moving Expenses, J. R. A.	545.10
Total	$3,191.98

Balance on Hand:

Petty Cash on Hand	16.86
Cash in Bank	704.66
Total	$721.52

BUDGET REPORT, A. S. H. & V. E. RESEARCH BUREAU

JANUARY 1, 1920

	Budget Allowance	Amount Received	Amt. Expended Checking Acct.	Budget Balance
Salaries	$11,000.00	$3,646.00	$2,146.00	$7,354.00
Office Supplies	500.00	212.51	212.51	287.49
Traveling Expenses	1,000.00	252.87	252.87	747.13
Heat Investigations	1,500.00	35.50	.35.50	1,464.50
Ventilation	......	......	......	......
Subsidizing Account	......	......	......	......
Moving Exp's, J.R.A.	......	545.10	545.10	......

No. 540

HEAT LOSSES FROM DIRECT RADIATION

By John R. Allen, Pittsburgh, Pa.

Member

IT is the purpose of this article to bring together all of the data which seem reliable upon the subject of heat losses from direct radiation. There have been many experiments made by different persons. Some of the results have been reported and some have been allowed to lie dormant. It is the intention of this article to bring together these various results in an endeavor to show the effect which the changes in the shape and size of a radiator, together with the conditions of operation, have upon the heat transmission. This article also discusses the theory of heat transfer from direct radiation and the effect of radiation and convection. All the results in the tables and figures are expressed in B.t.u. given off per square foot per hour and not in the form of a constant. The reason for not using a constant will be seen when the theory of heat transfer has been considered. In work of this kind it is not possible to give results with great accuracy but it is the author's opinion that in most cases the accuracy will be close to 5 per cent, and probably in all cases within 10 per cent.

HEAT LOSSES FROM A DIRECT RADIATOR

A direct radiator is one that is located in the room to be heated, has the air passed over it by natural circulation, and is not connected with the outside air. Direct radiators lose heat in two ways—by radiation and by convection. The heat loss by radiation is the heat which leaves the radiator independently of any heat carried away by the air circulating around the radiator. It passes from the radiator in straight lines in the same way that light passes away from a source of light, and it does not heat the medium through which it passes.

The loss by convection or contact of air is the heat which is carried away by the air coming in contact with the hot surface of the radiator and being heated. This air, when it is heated, rises, new air comes in to take its place, and we have formed, a current of hot air rising from the radiator. The heat carried away by this current of hot air is the heat lost by convection.

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, January, 1920.

In the following paragraphs will be found a discussion of the effect of various factors upon the heat loss from a direct radiator. In all of this discussion, the formula given in the latter part of the article has been used to check the curves that are given and in many cases has been used to extend the curves beyond the field of investigation. It is the intention to show the effect of different heights, lengths, and widths of radiators upon the heat transmission; also the effect of steam and room temperature, and various other factors that have appreciable bearing upon the heat transmission from direct radiators. It has been customary to assume that a

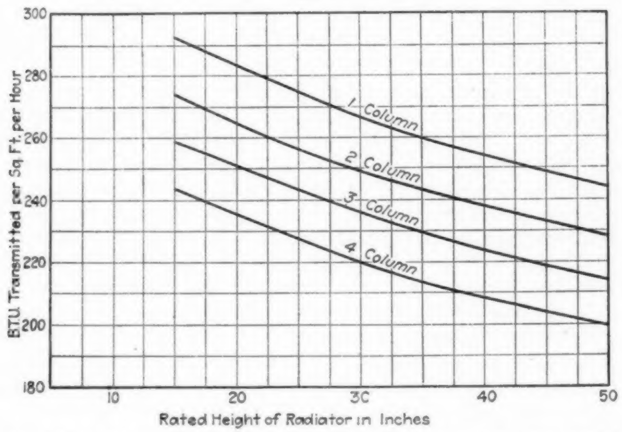

FIG. 1. HEAT TRANSMISSION FOR DIFERENT HEIGHTS AND NUMBERS OF COLUMNS OF RADIATORS

radiator lost about the same amount of heat irrespective of its form or size or condition of operation. It will be seen, however, that there are very wide ranges of heat transmission depending upon the conditions of operation.

EFFECT OF HEAT TRANSMISSION FOR DIFFERENT HEIGHTS AND NUMBERS OF COLUMNS OF RADIATORS

The width of a radiator is usually expressed as a certain number of columns and the height in inches from the floor to the top of the radiator. Table 1 and Fig. 1 show the heat transmission for cast-iron radiators in B.t.u. per hour per square foot of radiator surface in still air at 70 deg. with a steam temperature of 215 deg. The table is made up for radiators of 10 sections in length with different numbers of columns and height. For numbers of sections less than 10, as will be seen in a following paragraph, the heat transmission would be increased.

TABLE 1. B.T.U. TRANSMITTED PER SQUARE FOOT OF RADIATOR PER HOUR FOR DIFFERENT HEIGHTS AND NUMBERS OF COLUMNS

Steam Temperature 215 deg. fahr.—Room Temperature 70 deg. fahr.

Height of Radiator	1 Column	2 Column	3 Column	4 Column
45		233	218	204
38	256	240	226	210
32	265	247	234	218
26	273	255	242	226
23	278	260		
22			248	232
20	283	265		
18			254	238

EFFECT OF HEAT TRANSMISSION FOR DIFFERENT WIDTHS OF RADIATORS

The comparison of heat transmission through radiators by different numbers of columns is not strictly correct, as the effect is not due to the number of columns, but is more nearly due to the actual width of the radiator in inches. In order to show this effect, Fig. 2 has been drawn and from this figure has been compiled Table 2. This figure shows the effect of width of radiators on heat transmission under the same general conditions as in Fig. 1. It will be noticed that the heat transmission varies, depending on the actual number of inches in width even including pipe coils approximately, and will be found to compare very favorably with the actual experiments that have been made.

TABLE 2. HEAT TRANSMISSION FOR DIFFERENT WIDTHS OF RADIATOR EXPRESSED IN INCHES

Steam at 215 deg. fahr.—Room at 70 deg. fahr.—10 Sections of Radiator

Width of Radiator in inches	Height of Radiator			Width corresponds with
	20 in.	26 in.	38 in.	
3	310	297	288	Wall Coil
4½	287	274	258	Single Column
7⅝	264	251	236	Two Column
9	253	240	226	Three Column
12½	239	225	211	Four Column

EFFECT OF HEAT TRANSMISSION FOR RADIATORS OF VARYING LENGTHS

The effect on heat transmission of increasing the length of a radiator is shown in Table 3 and Fig. 3. The curves show that the length of a radiator has a marked effect when the radiator is under 6 sections in length. Above 10 sections the effect of length, in most cases, can be neglected without introducing any appreciable error. The reason for this may easily be explained. In the short radiators the effect of the end is much more apparent than in the long radia-

tors. The effect of the end is to increase the radiating surface in proportion to the convecting surface so that in a short radiator we get a larger proportion of radiant heat than in the long radiator. Curves are plotted for only two heights of radiator, as the relative effect of length remains practically the same in radiators of different heights.

A radiator may also be lengthened by increasing the spacing. A few experiments are available which show the effect of spacing. If the spacing of the standard two-column, 38 in. radiator is changed

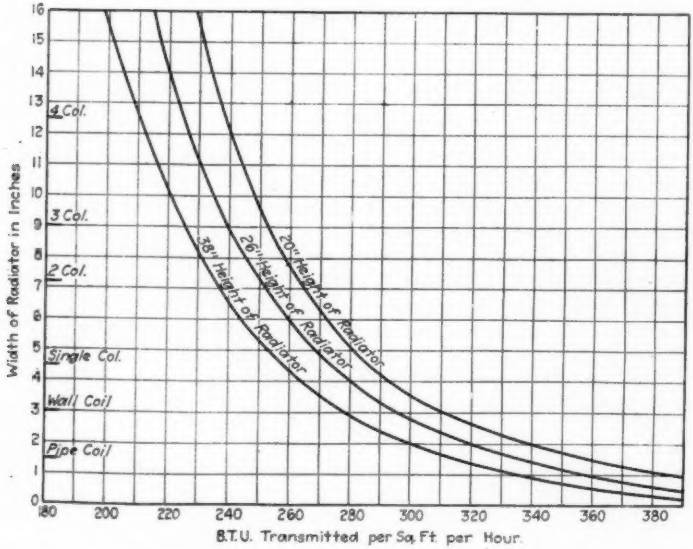

FIG. 2. HEAT TRANSMISSION FOR DIFFERENT WIDTHS OF RADIATORS

from 2 ½ in. to 3 in. the results show that the heat loss is increased about 7 per cent, which would correspond with the results obtained by using the general expression given at the end of this article. The hospital type of radiator is usually spaced ½ in. more than the standard type, so the hospital type may roughly be assumed to give off from 7 to 10 per cent more heat than the standard type.

EFFECT OF CHANGING STEAM AND AIR TEMPERATURES

The effect of changing the steam temperature on the inside of a radiator or the air temperature on the outside of a radiator has a very appreciable effect upon the heat transmission. The changing of the difference in temperature between the steam and air on the two sides of the radiator varies the transmission appreciably on ac-

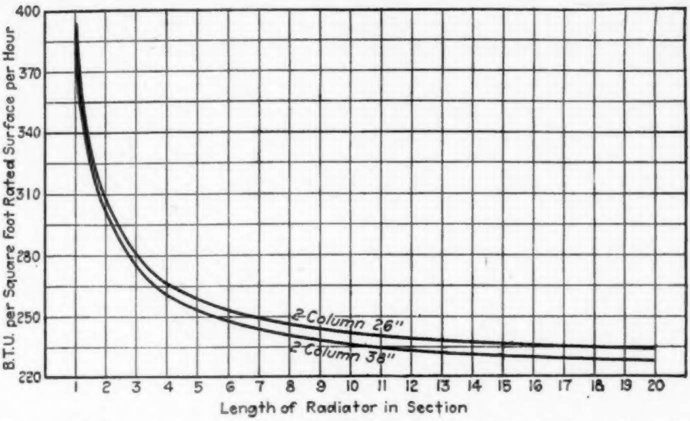

FIG. 3. HEAT TRANSMISSION FOR RADIATORS OF VARYING LENGTHS

count of the fact that the radiant heat transmitted varies as the fourth power of the temperature. Table 4 and Fig. 4 show the heat transmission for a two-column 38 in. radiator 10 sections long at different steam and room temperatures. This table and figure have been obtained from actual experiment but have been extended beyond the field of the experiment by the use of the formula derived

TABLE 3. HEAT TRANSMISSION FOR RADIATORS OF VARYING LENGTHS

Steam at 215 deg. fahr.—Room at 70 deg. fahr.

Length of Radiator in Sections	Height of Radiator			
	38 in.	32 in.	26 in.	23 in.
1	387.8	389.0	393.7	391.6
2	302.4	304.0	305.8	308.4
3	274.0	275.8	280.0	282.3
4	260.6	263.3	265.8	269.2
5	252.6	254.0	257.8	259.6
6	247.0	249.2	253.3	254.7
7	242.8	244.9	248.5	251.2
8	240.0	241.7	245.7	248.5
9	237.8	239.8	243.4	246.5
10	235.8	237.8	241.6	244.8
11	234.4	236.4	239.6	243.1
12	233.0	235.2	239.1	242.0
13	232.1	234.2	238.0	240.5
14	231.2	233.6	237.1	239.5
15	230.4	232.6	236.2	238.7
16	229.7	232.0	235.6	237.9
17	229.1	231.1	235.1	237.2
18	228.5	230.6	234.6	237.0
19	228.0	230.2	234.0	236.5
20	227.6	229.7	233.6	235.9

at the end of this article. It will be noted in looking at the plate that increasing the steam temperature increases the heat transmission more rapidly than reducing the room temperature.

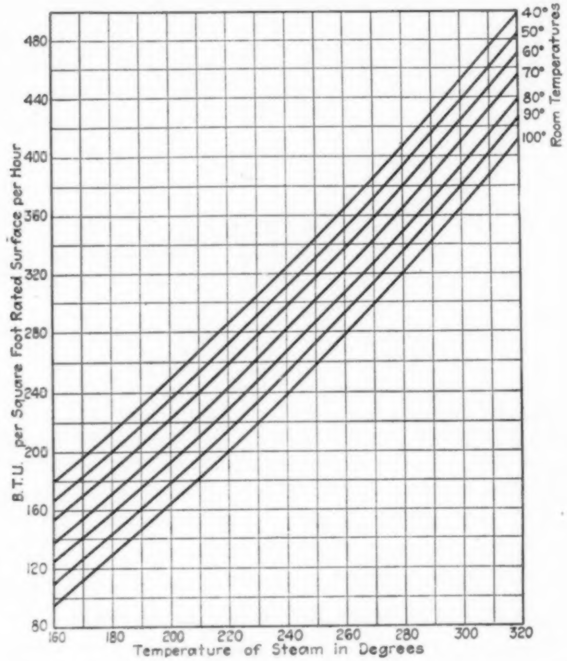

FIG. 4. HEAT TRANSMISSION FOR VARIOUS TEMPERATURES OF STEAM IN RADIATOR AND AIR IN THE ROOM

TABLE 4. HEAT TRANSMISSION FOR VARIOUS TEMPERATURES OF STEAM IN RADIATOR AND AIR IN THE ROOM

Temperature of Steam	Temperature of Air in Room						
	40	50	60	70	80	90	100
160	180	166.4	153.2	138.43	124.2	109.7	94.8
180	213	199.4	186.3	171.40	157.2	142.7	127.8
200	250	236.0	223.2	208.1	194.0	179.6	164.7
220	286.8	273.0	260.1	245.1	231.0	216.5	201.6
240	324.2	311.0	298.5	284.0	269.4	254.9	240.0
260	364.0	351.4	338.3	323.4	309.2	294.7	279.8
280	407.4	393.8	380.0	365.8	351.6	337.1	322.3
300	451.4	437.8	424.7	409.8	395.8	381.1	366.2

EFFECT OF HUMIDITY

Fig. 5 shows the effect of increasing the humidity upon the heat transmission. It will be noted that with extreme change of humidity there is a slight change in the heat transmission, the heat transmission reducing slightly as the humidity increases. Humidity can have very little, if any effect upon radiation, and the effect of humidity must therefore change the convected heat lost by the radiator. This change of convected heat is probably due to the change in the density of the air passing over the radiator.

EFFECT OF AIR CIRCULATION

The amount of heat given off by a radiator may also be increased by increasing the velocity of the air over the surface of the radiator. This increase in velocity will increase the amount of heat carried

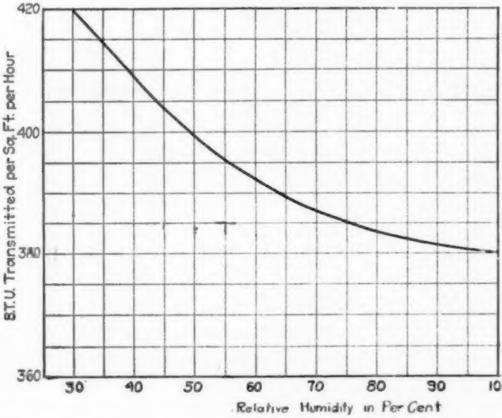

FIG. 5. EFFECT OF HUMIDITY ON HEAT TRANSMISSION

off by convection. No exact data are available on the effects that may be introduced by increasing these velocities over radiator surfaces, but in rooms with moving machinery the heat transmission may be increased as much as 10 per cent.

EFFECT OF PAINTING

The effect of painting was originally determined by experiments made with a cast-iron rectangle, and in applying these to radiators of standard type, corrections must be made to allow for the difference between the area of the radiating and convecting surfaces. The effect of painting is to change the radiation constant of the radiating surface and has practically no effect upon the heat lost by convection. It is, therefore, a surface effect and it makes no difference what paints are placed on the radiator as a priming coat; the re-

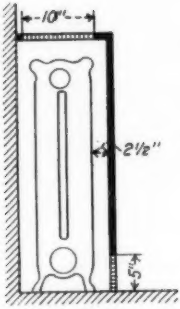

Fig. 6

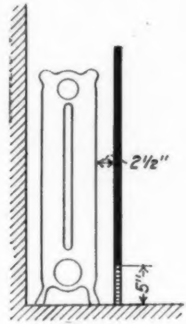

Fig. 7

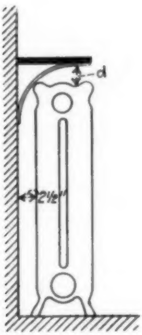

Fig. 8

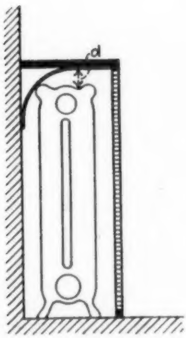

Fig. 9

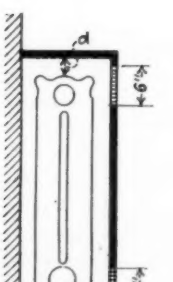

Fig. 10

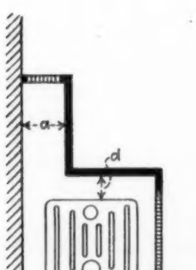

Fig. 11

DIFFERENT ARRANGEMENTS OF RADIATORS IN ENCLOSURES

sults are always dependent upon the last coat of paint put upon the radiator. In radiators having a large proportion of radiating surface such as pipe coils or wall coils, the effect of painting will be more marked than in four-column radiators having a comparatively small radiating surface in proportion to convecting surface. All finely ground materials have about the same radiation constant. Therefore all paints having finely ground pigments will give about the same effect. Metals have a poor radiating effect so that any paint containing flake metal, such as bronze, will have a low radiating constant. Table 5 shows the heat loss from a two-column 38 in. radiator, 10 sections long, when painted with different kinds of paints:

TABLE 5. EFFECT OF PAINTING ON TWO-COLUMN 38 IN. RADIATOR

Steam Temperature 215 deg.—Room Temperature 70 deg. fahr.

Condition of Surface	B. t. u. transmitted per square foot of radiator per hour.
Cast iron bare	240
Painted with aluminum bronze	200
" " gold bronze	205
" " white enamel	242
" " maroon japan	240
" " white zinc paint	242
" " no-lustre green enamel	230

EFFECT OF ENCLOSING THE RADIATOR

It is very often desirable to partly enclose or conceal a radiator by means of screens or grills. All such enclosures in general reduce the heat transmission from the radiator, the effect being both to reduce the radiant heat and the convected heat. As in most radiators the convected heat is at least two-thirds of the heat transmission, these enclosures or screens largely affect the convected heat. It is therefore very desirable that the current of air passing over and through the radiator should be restricted as little as possible. There has been some experimental work done, particularly abroad, with reference to these screens. There are, however, so many different cases that may arise that it will not be possible to discuss all of them but only to take up typical cases.

Case No. 1. In this case, Fig. 6, the radiator is enclosed in a box with a screen in front at the bottom, and a screen at the top, these screens extending the full length of the radiator. This arrangement reduces the heat transmission of the radiator from 7 to 10 per cent and in all cases, the spaces between the radiator and the wall and the spaces between the casing and the radiator should be at least 2½ in. The reduction of heat transmission will be more in narrow radiators than in wide radiators. Experiments show that the best results are obtained when the opening at the top has twice the width of the opening at the bottom, and for radiators of ordinary type the width of opening at the bottom should be 5 in. and the opening at the top, 10 in.

Case No. 2. It is sometimes desirable to place a screen in front of the radiator, leaving the top entirely open with an opening at the bottom in front for the cold air to enter the radiator, as in Fig. 7. In a case of this kind the effect of the screen is to produce a strong current of air and if this screen is high enough it may even produce a chimney effect which will increase heat transmission from the radiator due to increased circulation. The effect of such screens depends entirely upon their height. Professor Brabbee states that with a screen 72 in. high and a 49 in. radiator, the heat transmission will be increased 12 per cent.

Case No. 3. Radiators often have placed over them a flat shelf, as shown in Fig. 8. In such case, they should be provided with a deflector as shown. The effect of the shelf very largely depends upon the height of the shelf above the radiator. When the distance *D*— that is the height of the shelf above the radiator—is 5 in. or over, the effect of the shelf may be neglected. When the distance *D* is reduced to 4 in., the heat effect may be reduced by 4 per cent.

Case No. 4. Radiators are often enclosed in boxes with a grill in front or recessed in the wall with a grill placed in front of them as in Fig. 9. In such cases, the height, *D*, is very important. With *D* equal to 2½ in., the heat transmission will be reduced 20 per cent, and with *D* equal to 6 in., the heat transmission is reduced 10 per cent. It is assumed in this case that the entire front of the box is provided with an open grill.

Case No. 5. Sometimes a grill, as shown in Case No. 4, is partly replaced by a solid panel with openings above and below as in Fig. 10. With the openings the full length of the radiator and 6 in. in height and with *D* not less than 4 in., the heat transmission will be reduced 25 per cent. As *D* is reduced in height, the heat transmission will also be reduced and with *D,* 2½ in., the reduction will be 40 per cent.

Case No. 6. Radiators are often placed under seats as in Fig. 11. In this case the distance between the top of the radiator and the bottom of the seat becomes very important and should be not less than 3 in. and if possible it should be made 6 in. Under favorable conditions, when *D* is at least 3 in. and *A* is equal to 6 in., the heat transmission will be reduced from 15 to 20 per cent. When *D* is small, however, say 2 in., and *A* is reduced to 4 in., this reduction may be 35 or 40 per cent.

In tests[1] by Prof. K. Brabbee will be found other cases than those cited above.

EFFECT OF POSITION

The effect of position on the heat transmission of a radiator is a subject that has been investigated only to a very limited extent. The experiments that are available show that the heat loss from a radiator is about the same whether it is placed at the floor, at the

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[1] Reported by George Stumpf, Jr. in *Heating & Ventilating Magazine*, May, 1914, page 23.

ceiling, or in the center of the room. It seems to make very little difference whether it is placed close to the wall or in the middle of the room. Placing a radiator close to an outside wall heats the wall immediately behind the radiator and if no insulation is placed behind the radiator this may represent a loss of from 3 to 5 per cent.

WARMING THE RADIATOR

It is often very important to know the maximum condensation that occurs in a radiator when steam is turned on. Fig. 12 shows the condensation rate in pounds per hour for the time elapsing after

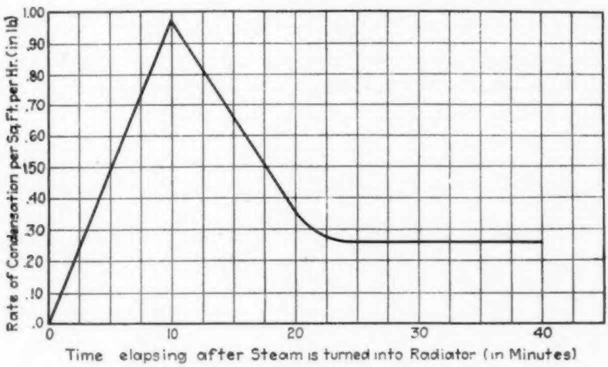

FIG. 12. RATE OF CONDENSATION WHEN STEAM IS TURNED INTO RADIATOR

steam is turned into the radiator. It will be noticed that the maximum condensation occurs 10 minutes after steam is turned on, and in that case it amounts to about 3½ times normal condensation. After the end of 25 minutes the radiator had reached a normal rate of condensation. This curve was made from observations at intervals of 10 minutes so that the intermediate points between the 10 minute points are not known, and the form of the curve is not exact. It shows, however, that in starting a plant, the demand made upon the boiler may be very much higher than the normal demand.

CONVECTION AND RADIATION

The importance of convection and radiation has been given very little consideration in heating literature. It may be more important than is realized as there is a distinct difference between heating by convection and heating by radiation. Where heating is done

entirely by radiation, the objects in the room and the walls receive the radiant heat and the air in the room is warmed by coming in contact with these warmer walls and objects. Therefore, in a room heated by radiant heat the air is always at a lower temperature than the objects in the room. If sufficient radiant heat were introduced into a room, it might be possible to feel quite warm in a room where the air was at a temperature considerably below 70 deg. The best example of heating by radiant heat is the open fireplace where practically all of the heat given to the room is by radiation. Radiant heat has the same properties in general as light, and we may have heat shadows the same as light shadows, so that in heating by radiant heat any object that does not receive the direct rays of the radiant heat will be at a lower temperature than the object that does receive the radiant heat. Therefore, in rooms of this character there must be a more or less unequal heating throughout the room.

When heating is done by convected heat the air enters the room at a higher temperature than the objects in the room and the objects

TABLE 7. RELATION BETWEEN RADIATED AND CONVECTED HEAT IN DIFFERENT TYPES OF RADIATORS. 10 SECTIONS IN LENGTH

Room at 70 deg. fahr.—Steam at 215 deg. fahr.

Number of Columns	Height of Radiator	10 Section Rated Surface	10 Section Area of inclosing Envelope	*R* Ratio of Radiating to Total Surface	Radiated Heat per sq. ft. Rated Surface	Total Heat per sq. ft. Rated Surface	Convected Heat per sq. ft. Rated Surface	% Convected Heat to Total Heat
One	38	30	15.9	0.53	106	256	150	58.6
"	32	25	13.5	0.54	108	266	158	59.4
"	26	20	11.1	0.555	111	273	162	59.4
"	23	16⅔	9.9	0.595	119	279	160	57.4
"	20	15	8.75	0.584	117	283	166	58.7
Two	45	50	21.45	0.43	86	234	148	63
"	38	40	18.35	0.458	92	240	148	62
"	32	33⅓	15.65	0.47	94	248	154	62
"	26	26⅔	14.00	0.53	106	255	149	58
"	23	23⅓	12.70	0.544	109	260	151	58
"	20	20	11.20	0.56	112	265	153	58
Three	45	60	22.90	0.382	76	218	142	65
"	38	50	19.7	0.394	79	226	147	65
"	32	45	16.85	0.375	75	233	158	68
"	26	37½	14.10	0.376	75	241	166	69
"	22	30	12.20	0.407	82	248	166	67
"	18	22½	10.35	0.46	92	254	162	64
Four	45	100	28.05	0.28	56	205	149	73
"	38	80	24.16	0.30	60	210	150	71.5
"	32	65	21.52	0.331	66	217	151	69.5
"	26	50	17.5	0.35	70	225	155	69
"	22	40	15.27	0.382	76	232	156	67
"	18	30	13.05	0.435	87	238	151	63.5
Wall Coil		5 Section						
5A	13 5/16	25	21.34	0.854	171	323	152	47
7A	21 7/8	35	27.24	0.78	156	310	154	49.7
9A	29 1/16	45	35.32	0.784	157	295	138	48

are heated by contact with the warmer air. It is therefore apparent that where a room is heated by convected heat, the objects in the room must always be at a lower temperature than the air in the room. In direct heating such as direct steam or hot water we have heating both by radiation and convection. It is possible by this means to have the objects and the air in the room at about the same temperature.

A study of the various forms of radiators is given in Table 7 which shows the proportion of radiant heat to convected heat in

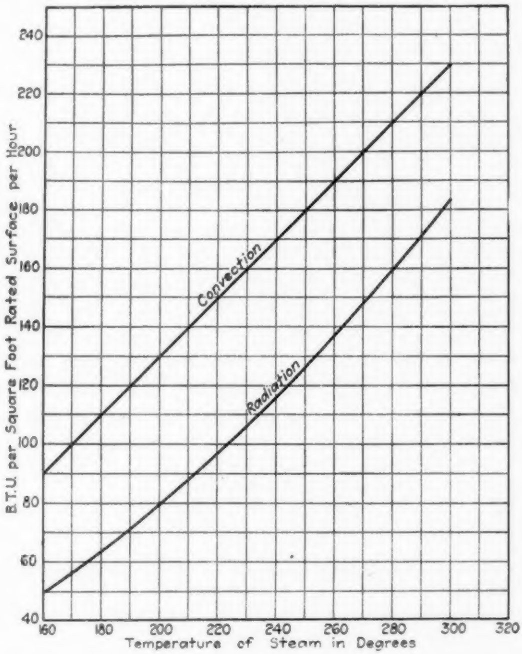

FIG. 13. HEAT TRANSMISSION BY RADIATION AND CONVECTION FOR VARIOUS TEMPERATURES OF STEAM

these various types. Radiant heat is greatest in a single horizontal pipe. The percentage of convected heat will be less in a wide radiator such as a four column type.

Column 5 in Table 7 shows the ratio of the radiating surface to the total surface of the radiator. Column 6 shows the radiant heat in various forms of radiators, and column 8 shows the convected heat. Column 9 shows the ratio of the convected heat to the total heat

given off by the radiator. It will be noticed in wall coils that about one-half the heat is given off by radiation and one-half by convection, while in a four-column radiator, about 70 per cent is given off by convection and 30 per cent by radiation. In a single horizontal pipe about 60 per cent will be given off by radiation and 40 per cent by convection. It is apparent from this table, that all radiators do not give exactly the same effects in heating a room, and that the effect of heating a room with pipe coils might be called heating with radiant heat while heating a room with four-column radiation might be called heating with convected heat, so that different forms of radiators might give appreciably different results depending upon the proportion of radiation and convection. It would seem that engineers should give more consideration to this question than has been done heretofore.

DERIVATION OF FORMULA FOR HEAT TRANSMISSION

A direct radiator gives off heat both by radiation and by convection, and it will be necessary in deriving an expression for heat transmission to have terms in the expression representing both radiation and convection. It will not be possible to combine these two terms as the surface radiating heat is not the same as the surface giving off the convected heat.

In the discussion that follows, it is assumed that the surface radiating heat in a direct radiator is the area of the parallelopiped enclosing the radiator, or putting it in another way, the surface radiating heat is the area of an envelope enclosing the radiator. This surface is independent of the rated surface of the radiator.

The radiant heat lost by the radiator may be figured by Stefan and Boltzmann's law and is expressed as follows:

$$Q_1 = D\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_r}{100}\right)^4\right] \qquad (1)$$

in which

Q_1 = B.t.u. radiated per square foot of radiating surface per hour.

T_r = Absolute temperature of the surrounding objects assumed to be the temperature of the room.

T_s = Absolute temperature of the radiating body assumed to be the temperature of the steam.

D = A constant depending upon the substance of which the surface of the body is composed.

(The value of D for cast-iron radiators may be taken as about 0.157.)

In order to reduce the *radiating* surface [1] to the *rated* surface so as to reduce all heat losses to the same units the factor R has been introduced. R = the ratio of the radiating surface to the rated surface. Expression (1) now becomes (for a cast-iron radiator) in B.t.u. per square foot of *rated* surface:

[1] That is, surface of enclosing envelope.

$$Q_1 = 0.157R\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_r}{100}\right)^4\right] \tag{2}$$

For example take a two-column 38 in. cast-iron radiator 10 sections long with steam at 215 deg., room temperature at 70 deg. Then:

$T_s = 215+460 = 675.$
$T_r = 70+460 = 530.$
$R = 0.458$, see Table 7, line 7.

Substituting these values in equation (2) we have:

$$Q_1 = 0.157 \times 0.458\left[\left(\frac{675}{100}\right)^4 - \left(\frac{530}{100}\right)^4\right] = 0.072(2075-789) = 93$$

where

Q_1= B.t.u. lost per hour per square foot of rated surface of the radiator.

In order to check the amount of radiant heat given off as determined by equation (2), a series of experiments was conducted on a radiator in an atmosphere of almost perfect vacuum. These experiments checked very closely with results given by equation (2).

The convection loss depends upon the difference of temperature between the air entering and the air leaving the radiator, also upon the density and velocity of the air passing the radiator.

The equation for convection may therefore be written as follows:

$$Q_2 = mqV(t_h - t_r) \tag{3}$$

in which

Q_2= B.t.u. lost by convection per square foot rated surface per hour.
m= A constant.
q= Density of the air passing the radiator.
V= Velocity of the air passing the radiator.
t_h= Temperature of air leaving the radiator. (fahr.)
t_r= Temperature of air entering the radiator. (fahr.)

Actual experiment show that t_h bears an almost constant ratio to the temperature of the steam. qV also bears an almost constant ratio to t_s. We can therefore write the expression for convection:

$$Q_2 = K_c(t_s - t_r) \tag{4}$$

in which

Q_2= B.t.u. lost by convection per square foot rated surface per hour.
K_c= The constant for convection which must be determined by experiment.
t_s= Temperature of the steam in the radiator. (fahr.)
t_r= Temperature of the air in the room. (fahr.)

Adding equation (2), the heat lost by radiation, to equation (4), the heat lost by convection, we have the total heat lost by the radiator. This expression for total heat loss becomes:

$Q = Q_1 + Q_2$ or substituting values:

$$Q = 0.157R\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_r}{100}\right)^4\right] + K_c(t_s - t_r) \tag{5}$$

Q = Total heat lost by the radiator.

For the ordinary forms of cast-iron radiation $K_c = 1$ and equation (4) becomes:

$$Q_2 = (t_s - t_r) \tag{6}$$

and equation (5) becomes:

$$Q = 0.157R\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_r}{100}\right)^4\right] + (t_s - t_r) \tag{7}$$

The values of R in equation (7) will be found in Table 7 for radiators 10 sections or more in length. For a shorter radiator it should be computed from the actual dimensions of the radiator.

In the case of a single horizontal pipe the value of R is 1 and may be considered a limiting case.

The use of the formula can best be shown by assuming an example in which we have a two-column 38 in. radiator 10 section, steam temperature 215 deg., room temperature 70 deg.

$R = 0.458$ then:

$$Q = 0.157 + 0.458\left[\left(\frac{675}{100}\right)^4 + \left(\frac{530}{100}\right)^4\right] + (215-70) =$$

$0.072\ (2075 - 789) + 145 = 93 + 145 = 238$ B.t.u. per sq. ft. per hour.

The actual figure taken from experiment is 240 which gives a difference of less than 1 per cent between the computed and the measured results.

Constant K. The usual expression for heat loss from a radiator is:

$$Q = K(t_s - t_r) \tag{8}$$

where K is a constant depending upon experiment.

This expression has a very limited application since t_r is usually 70, t_s usually from 215 to 225 and the most variable quantity in the expression is the constant K. Comparing equation (8) with equation (5) it is quite apparent that K must have a different value for every value of R. As R changes for every type of radiator, K must change. Also K will vary with every different value of t_s and t_r. It is therefore apparent that equation (5) will have a much wider application than would be possible with equation (8) which was originally deduced for a single horizontal pipe.

No. 541

DETERMINATION OF RADIANT HEAT GIVEN OFF BY A DIRECT RADIATOR

By John R. Allen, Pittsburgh, Pa. Member
and
Frank B. Rowley, Minneapolis, Minn. Member

IN order to develop a correct theory for the heat transmission from direct radiators, it is necessary to know the actual quantity of radiant heat given off by a radiator in comparison with the total heat transmitted. To obtain this information a series of tests has been conducted at the University of Minnesota to determine the radiant heat given off by a direct radiator.

A radiator gives off heat both by radiation and by convection and in order to determine the amount of heat given off by one or the other of these processes, it is necessary that one of them be eliminated. Convection depends entirely upon the movement of air surrounding the radiator and it seems reasonable that if the radiator were placed in a vacuum, the loss by convection would cease and the only heat that would be given off would be that transmitted by radiation. The law governing this heat transmission is known as Stefan and Boltzmann's law and one of the objects of these experiments was to compare the results obtained from Stefan and Boltzmann's law with actual experiments conducted on a full-sized radiator. Stefan and Boltzmann's law may be stated by the following equation:

$$Q = D\left[\left(\frac{T_2}{100}\right)^4 - \left(\frac{T_0}{100}\right)^4\right]$$

in which Q = B.t.u. radiated per sq. ft. per hour;
T_2 = Absolute temperature of radiating body;
T_0 = Absolute temperature of receiving body;
D = A Constant = 0.157 for cast-iron.

It will be noticed that in this equation there is a constant D which must be determined by experiment, and from these experiments this constant was determined.

In carrying out these experiments a two-column, 13 section, 38 in. cast-iron radiator was placed inside of a metal tank and the air

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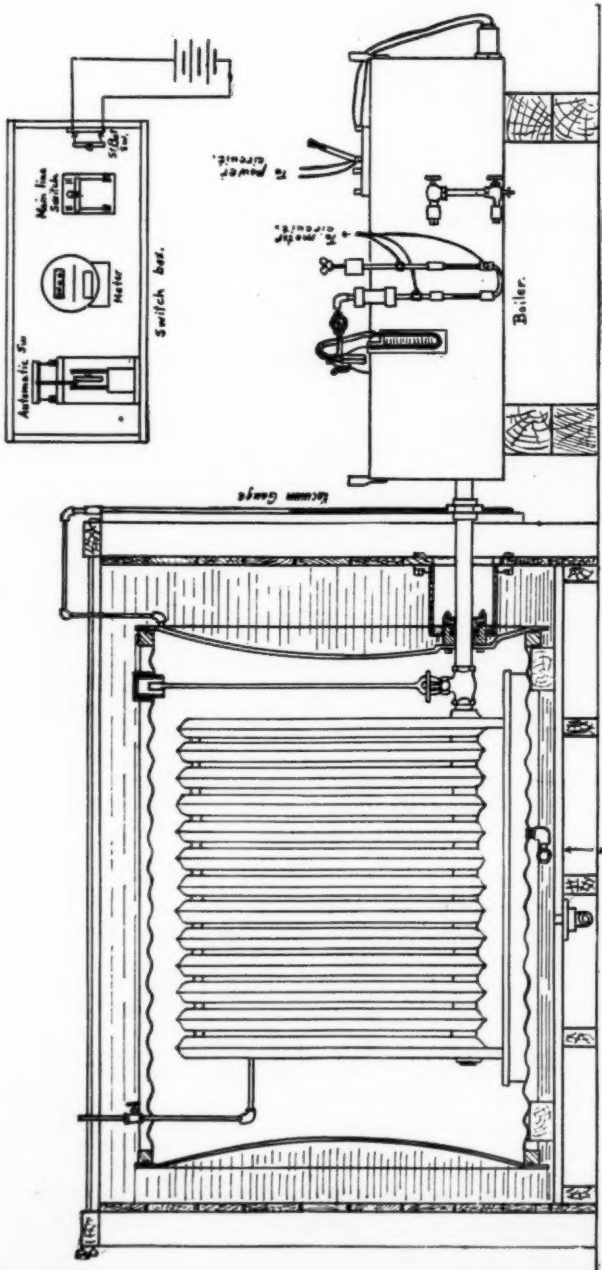

FIG. 1. SECTION THROUGH TANK SHOWING ARRANGEMENT OF APPARATUS.

was exhausted from the tank by means of a water ejector. The steam was supplied to the radiator by an electric boiler, all condensation being returned to the boiler. The electric input to the boiler was measured, and the boiler was carefully calibrated. The difference between the total input and the constant boiler loss was taken as the heat given off by the radiator. In all tests the boiler was steamed up, all air driven from the radiator and the system then operated for a sufficient length of time to insure uniform conditions before the test proper was started.

The arrangement of apparatus used can best be understood by referring to the accompanying photographs and drawings. Fig. 1 is a cross-sectional view of the vacuum tank, showing the surround-

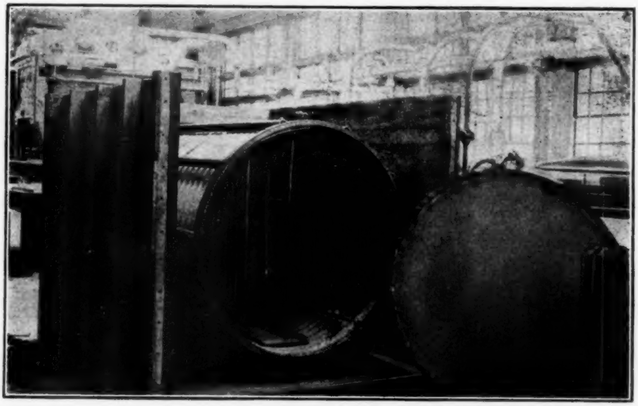

FIG. 2. VACUUM TANK WITH COVER REMOVED.

ing water and the radiator inclosed, together with a side elevation of the boiler. From the sectional view it will be noted that the radiator valve was placed close to the radiator in order to include all piping in the boiler calibration. The air line from the radiator and the vacuum gage connection are also shown. The steam pipe was passed through a stuffing box and protected from the water by a shield as shown. The pipe was well insulated between the stuffing box and the boiler. The vacuum line was taken from the bottom of the tank in order to prevent the tank from filling up with water if there should be any leaks.

Fig. 2 presents a view of the tank with cover removed, showing position of radiator and the construction of the tank. The tank was constructed of No. 12 gage corrugated iron with $1\frac{1}{2}$ in. square steel rings welded to each end. A $\frac{1}{2}$ in. groove in this ring formed the seat for a $\frac{1}{2}$ in. square rubber packing. The heads were made of $\frac{1}{4}$ in. dished steel plates and bolted to the ring by $\frac{1}{2}$ in. bolts, about $3\frac{1}{2}$ in. apart. Ten $1\frac{1}{2}$ in. pipes were placed on the surface of the tank between the rings to prevent the tank from

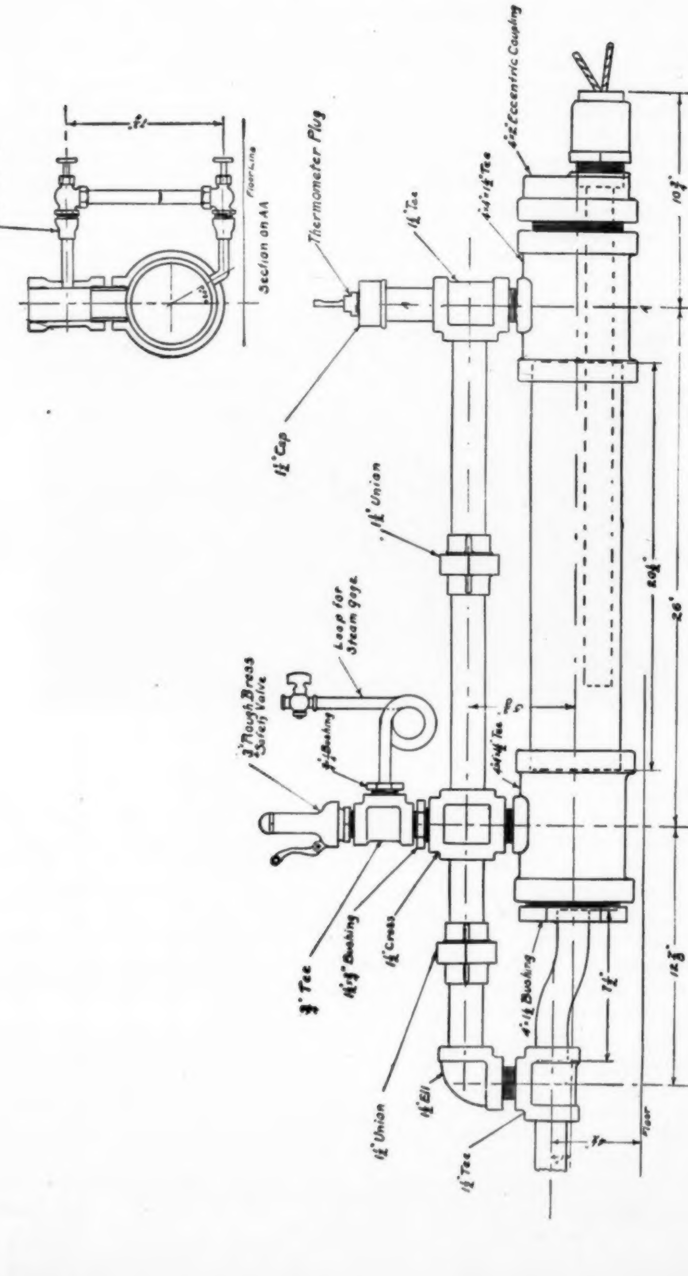

FIG. 3. DETAILS OF ELECTRIC BOILER.

collapsing end-wise. The inside dimensions of the tank were 42 in. diameter by 60 in. long. With this arrangement there was no difficulty experienced in maintaining a high vacuum.

Fig. 3 shows the detailed construction of the boiler. This boiler was built entirely of pipe fittings, placed in a wooden box and heavily insulated. The boiler was originally made for testing standard height radiators, therefore, the return line was kept 4½ in. from the floor line in order to use the standard radiator. This was accomplished by taking the steam off at the top and then bringing it down to the steam line as shown. A Westinghouse bayonet-type heating element was used, with a capacity of either 8,500 or 2,100 watts per hour.

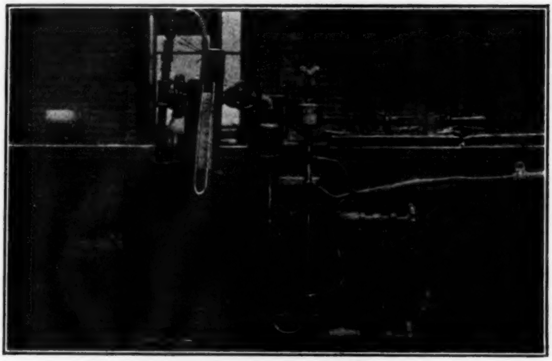

FIG. 4. SIDE ELEVATION OF BOILER AND MERCURY GAGE.

Fig. 4 shows a side elevation of the boiler and also the mercury gage used to measure the vacuum in the tank and the pressure element of the automatic boiler governor. The construction of this governor is shown in detail in Fig. 5 and 6. Fig. 5 represents the mercury column or pressure element on the side of the boiler. There are three wires leading from this column to the motor-driven switch shown in Fig. 6. As the pressure in the boiler drops, the mercury rises in the right-hand leg of the tube and closes the circuit between wires Nos. 2 and 3. This closes the battery circuit which operates the motor of the switch. The motor continues to operate until the worm wheel is turned through 180 deg. when the circuit is broken by the cam. This leaves a circuit between wires Nos. 1 and 3 closed at the switch and ready to operate as soon as the mercury column rises in the left-hand leg of the pressure tube The motor is driven by a storage battery and opens and closes the main switch supplying current to the boiler. Fig. 7 shows the motor-driven switch, meter, and main line switch. Single phase, 60-cycle, a. c. current was used for these tests.

Fig. 8 shows a sectional view of the tank giving the location of thermometers and thermo-couples used during the experiment. In

order to determine the average temperature of the water, 12 Leeds & Northrup thermo-couples were placed in the tank as shown and the average taken as the temperature of the water surrounding the tank. Two thermo-couples A and B were embedded in the inside surface of the tank and two others, C and D, were embedded in the outside surface to determine the surface temperatures. B and D were placed very near together. Fig. 9 shows details of the tank construction. Fig. 10 shows the details of the automatic switch.

Four series of tests were made, *first*, using a plain cast-iron radiator with rusty surface; *second*, surface covered with aluminum

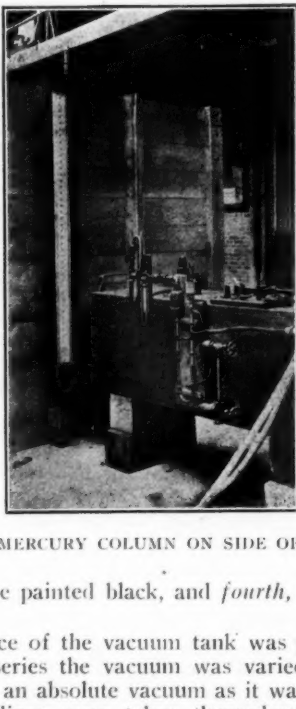

FIG. 5. MERCURY COLUMN ON SIDE OF BOILER.

paint; *third*, surface painted black, and *fourth*, plain cast-iron surface not rusted.

The inside surface of the vacuum tank was painted black in all tests and in each series the vacuum was varied from atmospheric pressure to as near an absolute vacuum as it was possible to obtain. The following readings were taken throughout all tests: Time; meter readings; vacuum in tank; barometric pressure; room temperature; temperature of water surrounding tank; and temperature of inside and outside of the vacuum tank.

The results of these tests are shown by the tabulated data and also graphically by the curves in Figs. 11 and 12. The curves in Fig. 11 show the heat lost per square foot of radiating surface per hour at various pressures in the vacuum tank. Curve No. 4 in this set shows the results of a plain cast-iron radiator surface without rust. Complete data were not obtained on this test; therefore they

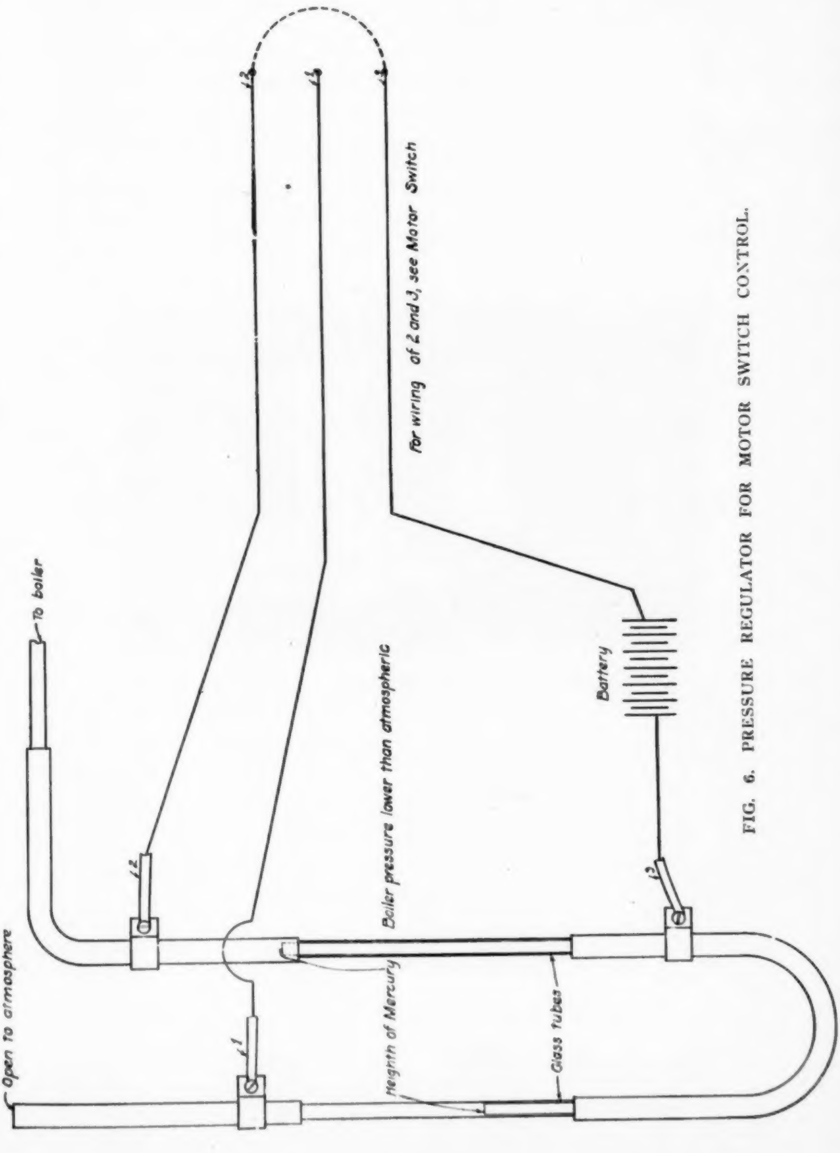

FIG. 6. PRESSURE REGULATOR FOR MOTOR SWITCH CONTROL.

are not recorded, but the curve is drawn to show their general relation to the others. The curves in Fig. 12 show the heat given off in B.t.u. per square foot of rated surface.

VALUE OF RADIATION COEFFICIENT

From the data obtained in these tests it is possible to determine approximately the value of radiation coefficient in Stefan and Boltzman's law. Table 1 shows the results obtained.

These results show a difference of about 10 per cent in the value of D as determined from a full sized radiator and the value of D as determined by the physical experiments. This difference may be

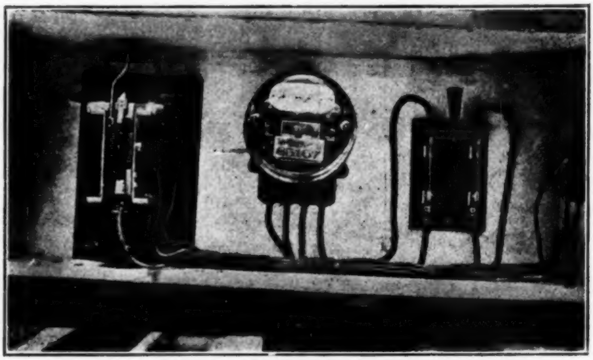

FIG. 7. MOTOR-DRIVEN SWITCH, METER AND MAIN LINE SWITCH.

accounted for in two ways: *First,* by the limits of error of the test, and *second,* by the fact that it has been assumed that the envelope surrounding the radiator was the surface from which radiant heat is transmitted. The fact, however, that these results show such close coincidence to Stefan and Boltzmann's law is evidence to confirm the statement that the radiant heat loss in ordinary radiators depends approximately on the enclosing envelope and not on the rated surface. This statement has also been made by Mr. L. C. Soule in his discussion on the report of the Committee on Standard Methods of Testing Radiators.

TABLE 1. DATA FOR DETERMINATION OF RADIATION COEFFICIENT

Condition of Surface	Temp. of Tank Surface	Temp. of Steam	B.t.u. per sq. ft. Radiating Surface	Value of Constant D
Cast iron, rusty	70	215	180	0.142
Cast iron, painted black	70	215	152	0.130
Cast iron, clean	70	215	186	0.148
Aluminum paint	70	215	131	0.104
Physical experiment, clean cast iron	70	215	198	0.157

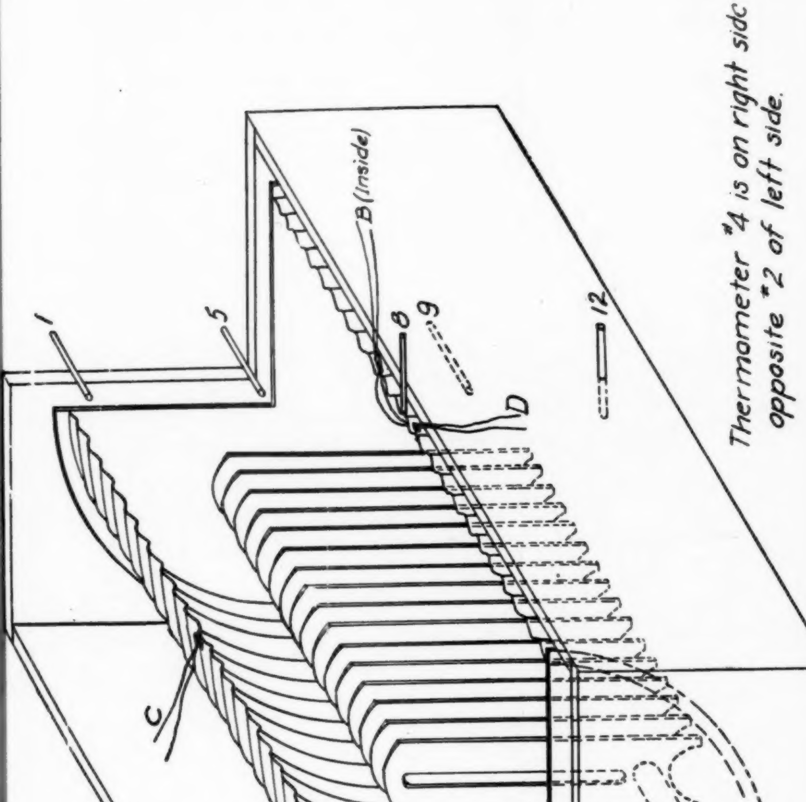

FIG. 8. SKETCH SHOWING ARRANGEMENT OF THERMOMETERS.

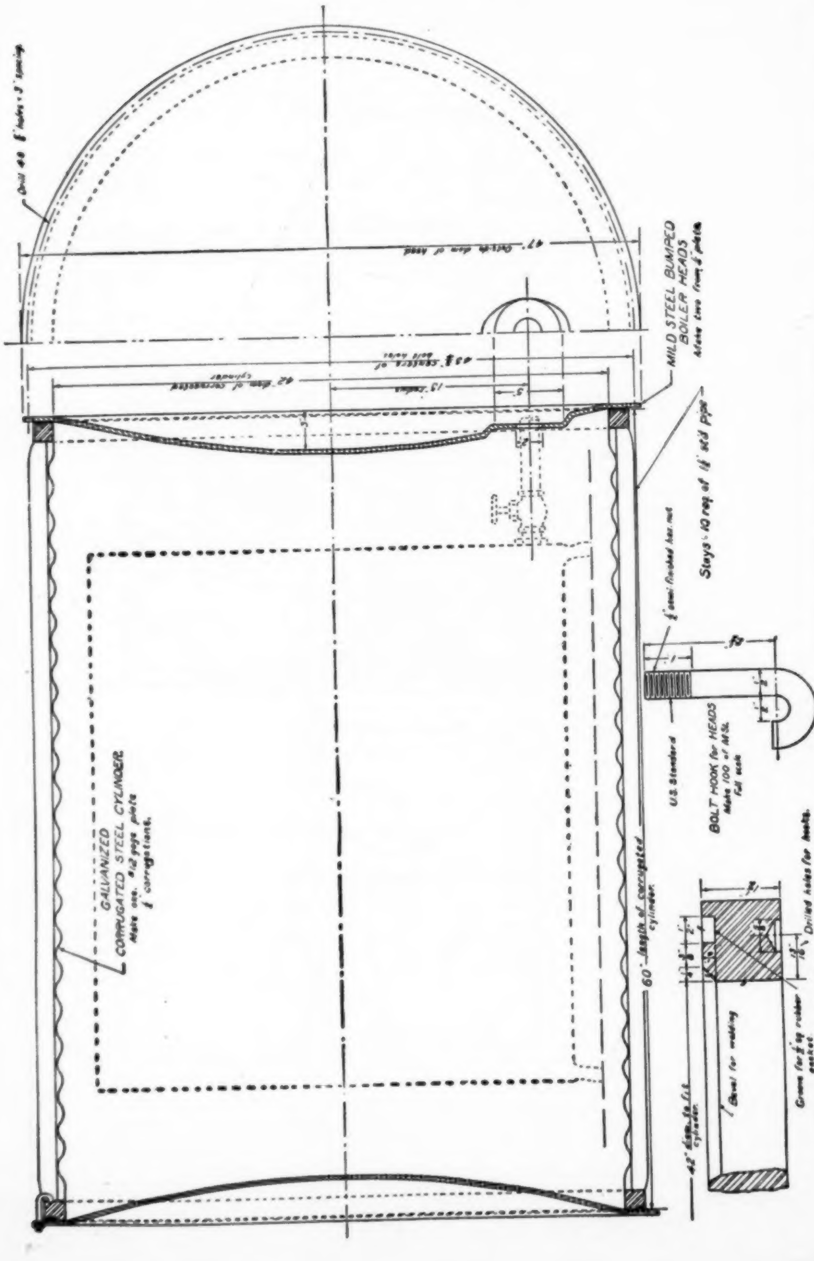

FIG. 9. DETAILS OF CONSTRUCTION OF VACUUM TANK.

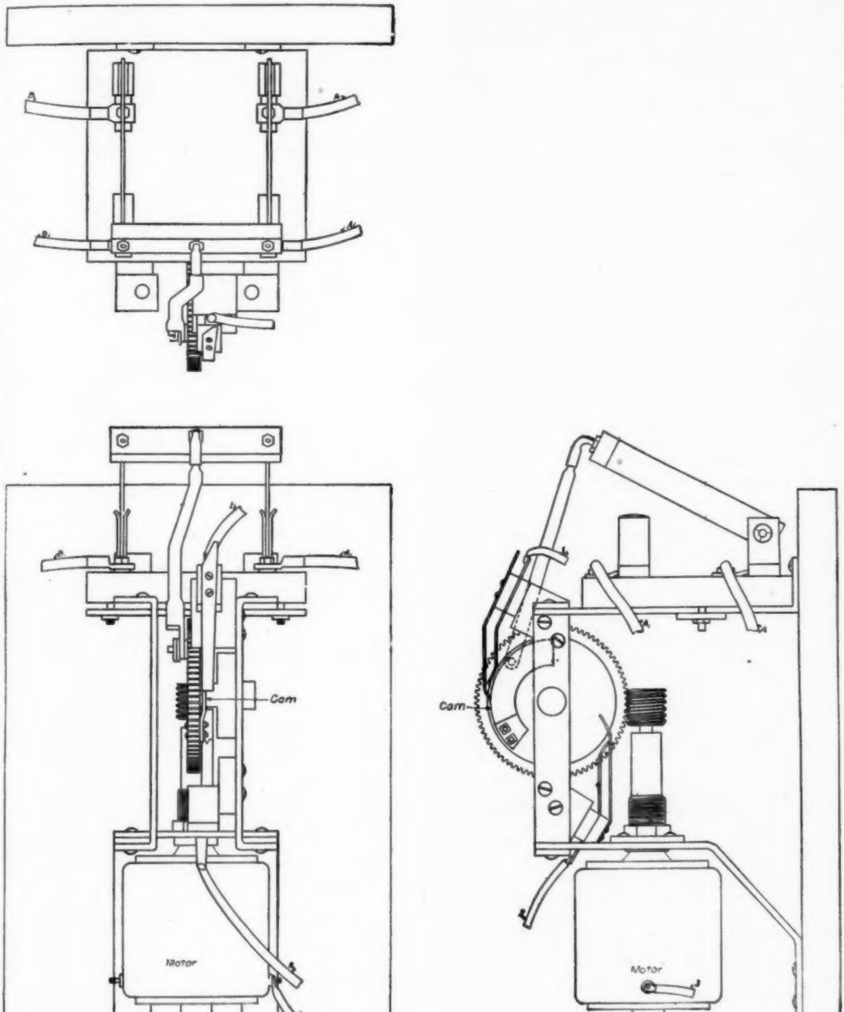

FIG. 10. DETAILS OF MOTOR SWITCH FOR BOILER PRESSURE CONTROL.

TABLE 2. TEST SERIES NO. 1—RUSTY SURFACE WITHOUT PAINT

TEST No.	1	2	3	4	5
Absolute pres. in tank, in. mercury.	0.13	5.53	10.77	19.55	29.44
Meter input k.w. per hr.........	1.8750	2.3625	2.6333	3.0333	3.3500
Heat input, B.t.u. per hr........	6403.1	8067.9	8992.7	10358.7	11440.2
Boiler consumption B.t.u. per hr.	1691.6	1691.6	1691.6	1691.6	1691.6
Net B.t.u. input per hr.........	4711.5	6376.3	7301.1	8667.7	9748.6
B.t.u. per sq. ft. of radiating surface per hr.................	90.7	122.5	140.4	166.6	187.6
Temp. of tank surface inside, deg.	36.71	49.61	52.71	56.23	56.67
Temp. of tank surface outside, deg.	35.10	46.38	47.96	49.51	50.83
Temp. cooling water, deg.......	34.09	42.89	38.70	39.54	40.21
Temp. of room, deg.............	62.1	59.57	60.56	61.66	61.80
Barometer readings..............	29.24	29.47	29.45	29.44	29.44
Temp. of steam, deg............	216	216	216	216	216
B.t.u. per sq. ft. radiating surface per hr......................	206	279	320	379	427

TABLE 3. TEST SERIES NO. 2—WITH ALUMINUM PAINT

TEST No.	1	2	3	4	5
Absolute pres. in tank, in. mercury.	0.57	3.82	13.81	19.88	29.36
Meter input k.w. per hr.........	1.466	1.810	2.3217	2.5250	2.8125
Heat input, B.t.u. per hr........	5000.	6180.	7920.	8622.	9620.
Boiler consumption B.t.u. per hr.	1691.6	1691.6	1691.6	1691.6	1691.6
Net B.t.u. input per hr.........	3308.4	4488.4	6228.4	6930.4	7928.4
B.t.u. per sq. ft. of radiating surface per hr.................	63.6	86.3	119.8	133.3	152.4
Temp. of tank surface inside, deg.	57.32	60.73	61.75	62.17	65.79
Temp. of tank surface outside, deg.	53.50	53.87	53.68	54.98	58.47
Temp. of cooling water, deg.....	44.45	46.31	47.68	49.04	50.11
Temp. of room, deg.............	64.83	68.37	70.56	69.66	68.89
Barometer readings..............	29.39	29.37	29.36	29.36	29.36
Temp. of steam, deg............	216	216	216	216	216
B.t.u. per sq. ft. radiating surface per hr......................	145	197	273	304	347

TABLE 4. TEST SERIES NO. 3—WITH BLACK PAINT

TEST No.	1	2	3	4	5
Absolute pres. in tank, in. mercury.	0.3	4.27	15.18	20.87	29.05
Meter input, k.w. per hr.........	1.7900	2.225	2.7375	2.925	3.3593
Heat input, B.t.u. per hr........	6146	7594	9350	9985	11460
Boiler consumption B.t.u. per hr.	1691.6	1691.6	1691.6	1691.6	1691.6
Net B.t.u. input per hr.........	4454.4	5902.4	7658.4	8293.4	9768.4
B.t.u. per sq. ft. of radiating surface per hr.................	85.7	113.5	147.2	159.5	187.8
Temp. of tank surface inside, deg.	49.83	51.12	55.22	57.92	59.71
Temp. of tank surface outside, deg.	46.31	47.66	47.77	55.78	47.76
Temp. of cooling water, deg.....	41.34	42.51	42.27	47.65	38.91
Temp. of room, deg.............	68.37	66.43	68.93	68.5	69.67
Barometer readings..............	29.28	29.16	29.16	29.08	29.05
Temp. of steam, deg.............	216	216	216	216	216
B.t.u. input per hr. per sq. ft. of radiating surface..............	196	258	335	363	428

In computing the radiant heat loss from a radiator, it would seem, then, sufficiently accurate to assume the value obtained from physical experiments, namely—0.157 for cast iron. If this value were assumed with a steam temperature of 215 deg. and the surrounding objects at 70 deg., the heat lost by radiation is approximately 200 B.t.u. per sq. ft. of rated surface.

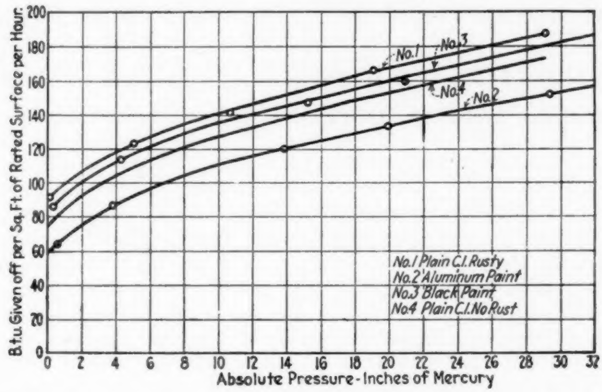

FIG. 11. VARIATIONS IN HEAT LOSS WITH DIFFERENT SURFACES UNDER VARIOUS DEGREES OF VACUUM

In Fig. 12, compare Curves No. 1 and No. 2. It shows that the difference in value between a radiator with and without aluminum paint remains almost the same for different conditions of vacuum. This means that at different vacuums, the radiation loss remains a constant and the effect of vacuum is to change the convection only. It also shows that the effect of painting radiators is a surface effect and depends upon the radiation constant.

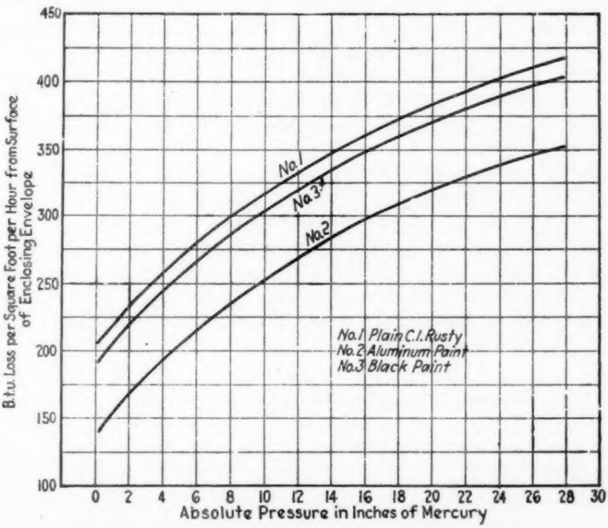

FIG. 12. VARIATIONS IN HEAT LOSS UNDER DIFFERENT DEGREES OF VACUUM

HEAT LOSSES FROM DIRECT RADIATION, by J. R. Allen, AND DETERMINATION OF RADIANT HEAT GIVEN OFF BY A DIRECT RADIATOR, by J. R. Allen, and F. B. Rowley.

JOINT DISCUSSION

THE AUTHOR (J. R. Allen): For some years I have been interested in the separation of radiant and convected heat in radiators. A radiator loses its heat in two ways, by radiation and by convection. Radiant heat is the heat that passes from a radiator as light passes from a source of light; it does not heat the medium through which it passes and the heat is not useful until it is absorbed by some body, and in turn that heat is taken by convection from that body. Convected heat is the heat that is carried away from the radiator by contact with air, that is, by a current of air formed by the heating of the air along the radiator surface.

Now heat is a very elusive thing and I tried for many years to find out the amount of convected heat lost by a radiator. About two years ago I reversed the process and threw away all the results on convected heat and tried to separate radiant heat. We must eliminate one in order to find out the other.

In studying these papers it must be remembered that the surface which gives up radiant heat is not the same surface that produces convected heat. Radiant heat is lost from the normal surface of the radiator, that is of an envelope that just encloses the radiator. If you should wrap the radiator in a piece of paper that just fitted it on the outside, the area of that piece of paper would be the radiating surface, and I have called this surface the enclosing envelope. Heat is radiated from this enclosing envelope; the convected heat is given off from the rated or actual surface.

In Figs. 11 and 12 the lower figures show the heat losses for different vacuums based on the radiating surface—this was arranged in order to show the final results. It will be noticed that the heat loss dropped rapidly as the vacuum increased. Now when all the air has been removed which was practically done at ½ in. of mercury, there was no convection, because convection depends on movement of air, and if there is no air present, the assumption is that the heat loss is all by radiation.

The summary of results is shown on page 39. One thing I want to point out in connection with the results is that the only significant figure, so far as radiation is concerned, is the figure given in the first column of the last line. The other figure is used only to produce the curve.

When we get the lowest possible vacuum, we can then extend the curve to a perfect vacuum, and assume that that is the amount of heat given off by radiation as distinguished from convection. The upper curve shows the actual heat loss based on the entire radiating

surface of the radiator. Speaking roughly, we found in a two-column radiator about 30 per cent of the heat lost from the radiator was given off by radiation and 60 per cent by convection.

You will note the effect of paints on the radiator. The paints affect the radiation only and not the convection loss. On the basis of actual radiating surface, the B.t.u. loss per square foot of radiating surface in the first case was 206, in the second case, with aluminum paint, 145, and with black paint 196. That is the heat loss per actual square foot of radiating surface.

With those results in mind and with the experiments available on direct radiators, I wrote the paper on page 11, showing the effect of height, of width, of length, and of the various factors which enter into the amount of heat lost by the radiator. In Fig. 1 the heat loss from radiators for varying heights and numbers of columns is shown. From the table one can find almost all the heat losses of almost all the common forms of radiators in use. The curve is tabulated on the opposite page. You will notice that the two column and the three column radiators are rather close together and that those curves are not quite equally spaced. You will see in a moment the reason for it. The heat loss would be about the same whether the radiator was four columns or one column, if they were the same width. On page 14, is shown the curve for the heat lost from radiators of three different heights and various widths. This curve shows that the heat loss from a radiator depends more upon width than the number of columns. This curve extended to the narrow widths gives approximately the results for the pipe coil, but not quite so close as for the radiator.

There is one thing that is often lost sight of, and that is the question of the effect of the length of the radiator. Of course as the radiator is made shorter and shorter there is more radiating surface and less convecting surface, and we correspondingly have quite a different heat loss. On page 15 I have plotted the effects of various lengths of radiators. Now if there were such a thing as a single section radiator the heat losses are seen to be almost 400 B.t.u. per sq. ft. They run up to almost equal to the single horizontal coil. As more sections are added to the radiator the heat loss drops rapidly; when there are six sections, the number of sections does not make much difference, and beyond ten sections, an increase in the number of sections makes practically no difference in the heat loss. The very short radiators are very much more effective than the longer ones.

The effect of temperature inside and outside the radiator should be considered. I want to point out one thing: I have not used the constant K in this article. I have abandoned this constant, as I will show you a little later. On page 16 there is a curve showing the heat losses for different temperatures of the room and for different steam temperatures. The increase of steam temperature is more effective in increasing heat loss than a decrease of room temperature, so that the spacings between the curves for different

room temperatures are much smaller than the spacing for the differences of steam temperatures. This table is constructed for a two-column 30-in. radiator. A similar table could be constructed for any form of radiator.

On page 17, I have shown the effect of humidity on heat loss. That curve is more interesting than useful, because as a matter of fact we never get humidities as high as shown there. These experiments were made in a room under very artificial conditions. They show that with very high humidities a decreased heat loss is obtained. The reason for that of course is obvious. Convection depends on density and velocity. If the density is increased, the convection is reduced; the more water put in the air, the less density—hence the less heat loss.

The summation of the entire paper is on page 22, in Table 7, which shows the relation between radiation and convection in the various forms of radiators. I have shown the radiation and convection losses for radiators from one to four columns in the different heights manufactured, including wall coils. The fourth column shows the area of the enclosing envelope; that is, the area of the surface from which heat is radiated; the next column shows the relation between that surface and the actual surface of the radiator, which I have called the factor *B*, and of which I will speak later. That is the index number for each type of radiator and is an important consideration in figuring heat loss. Column five shows the amount of radiated heat for different types of radiators. Column six is the total heat given off, determined by experiment, and the next to the last column is the difference between the two, or the convected heat. You will notice that the convected heat remains substantially constant. The last column shows the percentage of convected heat as compared with the total heat given off.

It will be noticed that for a four-column 30-inch radiator or a four-column 45-in. radiator, 73 per cent of heat are given off by convection and 27 per cent by radiation. That radiator is a convector; it is not a radiator. In a wall coil of the 5-A type there are 47 per cent given off by convection and 53 per cent given off by radiation. That is a radiator. Now the different forms of radiators come in gradations between, so heating by wall coil or heating by four column radiation makes a distinct difference. They represent two different types of heating plant, in degree, at least. We have given no consideration to the question whether we shall use radiant heat or convected heat, and yet there is an essential difference. Obviously in a room heated with radiated heat, it is necessary for the radiant heat to be absorbed by objects in the room and the walls, and in turn the air, warmed from the walls and objects in the room; therefore the air in the room must be at a lower temperature than the walls of the room. If a room is heated with convected heat, the air is at a higher temperature than the objects and walls of the room. Now whether radiant heat or convected heat should be used for heating a room is a question the heating

engineer must decide. Perhaps a combination of both should be used.

On page 21 of the second paper, there is shown the effect of turning steam into the radiator quickly. The maximum condensation occurs about 10 min. after turning on the steam, and then it slowly drops back to the normal. This shows that the maximum condensation can be almost four times the average condensation, so in starting up a plant it may be necessary to take care of almost four times as much condensation as in ordinary operations.

The curve in Fig. 7 shows the relation between the radiant and convected heat for different temperatures.

We have assumed, for a great many years, that the heat loss was a certain constant called K, times the difference between the room temperature and the steam temperature. The room temperature as radiation is ordinarily figured is assumed as 70 deg., and the steam temperature runs from 215 to 225 deg. in most buildings. The temperature difference is almost a constant, and the only variable in that equation is therefore the constant —— that constant varies 100 per cent! The only logical way to analyze a radiator is to get a funda mental expression for radiation and for convection, and then add these two together for the heat loss.

The constant for radiation was found at the University of Minnesota and an expression was written for radiation using this constant. To this was added the expression for convection and the sum is the heat loss from the radiator given on page 25. The constant K_c in the equation came out to be approximately 1. It runs from 1.03 to 1.06, and for ordinary purposes may be called 1. This gives equation (7), which is the equation that was used to determine heat loss in this article. R will be found in the table given on page 22, which gives R for all the different types of radiators. This factor R substituted in the equation with the proper steam and room temperature for a given case will give the heat loss from any radiator under the given conditions. This equation applied to the ordinary radiators on the market will give results within 5 per cent of the actual heat losses determined by experiment. The expression seems to have a fairly universal application to heat losses in radiators, which is much better than the old factor K that varied 100 per cent for different types.

The principal thing I want to bring out at this time is the question of radiation versus convection. Should we use radiated heat or convected heat or should we use a combination of both? This question should be given consideration by heating engineers. There are many experiments that go to show that there is a difference between different types of radiators in the amount of heat available in the room. All of our experiments in heat losses from radiators have been made to determine how much heat the radiator would give out; not, how much heat does the radiator leave in the room. That is a question that requires still more study. But with the knowledge we have at the present time, in regard to radiated and con-

vected heat, we can proceed to make a study of the amount of heat that is actually left in the room.

PERRY WEST: I would like to ask in connection with the tables on page 38 of the second paper, if the figures in the last line, that the author referred to as significant, have any particular relation to the heat given out by a radiator in an ordinary room. As I understand it, the radiators being tested were in a tank and in a temperature that is not an ordinary room temperature. In other words, the room temperature had nothing to do with the temperature in this tank. For instance, in the first table at the top of the page.

THE AUTHOR (J. R. Allen): That is purely an arbitrary figure. The significant figures are those in column one, 206, 145 and 196.

L. C. SOULE: Referring to the formula on page 25 of the first paper, the equation reads $Q_2 = K_c(t_s - t_h)$. If we assume K_c is equal to approximately 1, I would like to inquire why the convected heat in the Table is not nearer the constant of 145 (the difference between steam temperature at 215 and the room temperature of 70). It seems to me there is a great variation in the values given in that column for convected heat per square foot of radiation surface, and must mean that the constant K_c would have a variation of perhaps 20 per cent.

THE AUTHOR (J. R. Allen): That is a good question. K_c has undoubtedly a variation. We have not conducted experiments enough to know what the variation is at the present time. The constant figures out, as I said 1.01 to 1.03 and I have called it 1.

L. C. SOULE: In that same Table 7, in the column of convected heat per sq. ft. radiated surface, it seems like an unusual variation to have a value of 154 B.t.u. for 7-A, while 9-A gives 138, whereas the variation between 5-A and 7-A is only 152 and 154.

THE AUTHOR (J. R. ALLEN): It looks so to me. I couldn't find any error. I think it is due to the fact that the tests available were not accurate, particularly due to the fact that a wall coil is a hard thing to test, because of the large amount of radiated heat. All kinds of results can be obtained, depending on the room a radiator is tested in. If a radiator is tested in a greenhouse one result will appear and in an icehouse an entirely different result owing to the difference in radiated heat. What we need now, if we want to get very accurate results, is a standard test room. The Bureau proposes to build a constant temperature room, where all conditions are uniform, and then we can get results that are absolutely comparable.

PERCY NICHOLLS[1]: Professor Allen has done a great service in bringing results of experiments nearer to the fundamental laws under which the actions occur, but an interesting question is as to whether the investigations show signs of reaching finality. In looking up work done by engineers during the past 25 years, one cannot but be

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struck by the apparent lack of finality as one sees the same subject taken up again and again by sundry investigators.

What is needed for finality? Is it not that the actions must be divided up into their integral parts, so that each is evaluated on the basis of the fundamental law causing that particular action? On that basis of knowledge we should be able to arrive at the total results by a summation of the small parts, and believing in the unit would trust the total.

When one compares the comparative finality reached by physicists 100 and 180 years ago, with a money investment very small compared with what we put into our work now, one is inclined to think that we may have lost the correct view-point. Certainly we have not attached the same importance to fundamentals that they did, and it is an interesting commentary that 75 years ago a French physicist investigated the losses through and from hot surfaces and expressed his results, by dividing them into radiation and convection and included all factors such as shape, position, temperature of surface, air and walls. In those days, they seemed to have had greater faith in 2 plus 4 equaling 6 or 3 times 4 equaling 12 than we have, and I believe we could use their methods and types of apparatus more or at least could advantageously supplement our own larger scale practical investigations.

Prof. Allen has made a step forward for radiators, but I would question whether his equations could not conform more to fundamentals. For instance, the equation for convection is $Q_2 = qV (t_h - t_r)$; Surely the specific heat of air should come in.

His radiation factor is based on the envelope area. Should not or could not it be based on the effective radiating area in its relation to exterior objects? If the radiators were a series of thin flat-plates there should be no radiation except from the ends.

The idea I would leave is this: that finality will only be reached when one can apply fundamental laws, with their constants fixed by experiments, to any shape, in any position and with any surrounding conditions. In tackling such a problem the radiation factor is the easier one, as it is surely based on definite laws, which must be simpler than those for convection.

Prof. Allen requested that the discussion consider radiation versus convection as a means of heating. There was a paper read by Mr. A. H. Barker in 1915 before the *Society of Engineers*, London, which describes an instrument for separating these values at any point in a room. He also goes into the psychological effects of radiated versus convected heat, and personally I agree with his conclusions, that more radiation and a lower air temperature would be more healthy, and I believe that at present we are working too far in the other direction.

P. J. DOUGHERTY: I surely am in favor of getting back to fundamentals, which is the crying need among the engineers of today. The heat contained in the steam is given off by the radiator by convection

and by radiation. When one of these factors is eliminated, convection, as was done in this test, what effect has it on the other factor, radiation? That is the thought that occurred to me when the author established the ratio between radiation and convection.

THE AUTHOR (J. R. Allen): I was perplexed there and asked myself that same question a good many times. I think that is true. If a very fine pyrometer is put on the surface of the radiator you will find that the surface of the radiator is very close to the temperature of steam. That being the case, the small hole in getting the heat out of a radiator is at the surface of the radiator. Now if the surface of the radiator remains the same the radiator remains the same, whether there is convection or not.

B. S. HARRISON: It occurs to me that radiant heat can be considered static heat and the heat of convection as velocity (dynamic) heat, just as there are static pressure and velocity pressure in the duct. In other words, the radiant heat is convertible to heat of convection very readily, and practically all the heat can be carried off that way. The condition obtained in Professor Allen's test corresponds to the results that a good many have obtained handling "convectors", to use Professor Allen's term.

I have been very much isterested in that end of it, particularly, for a long time; and the results that I have had correspond very closely to the results which Mr. Carrier has given out before the Society; that is, the curve of convection varies with the cube root of the velocity square very closely. It does not seem to me that there can be very much error in Prof. Allen's figures on the proportion of radiant heat to total, as the radiant or static heat is not converted (in this case) to heat of convection or velocity heat, because of the vacuum.

E. H. LOCKWOOD: It seems to me, while this presentation is of very great interest and of great value, I cannot help feeling that at the present time, we hardly need this refinement of analysis as long as the results of radiator testing are so variable. Professor Allen admits that it depends much on the conditions in the room, that is, in one room a certain result is obtained, and with slight changes, such as screening the windows, a different result is secured. Hence, I am not impressed with the practical importance of a rigid, close analysis of the heat given off when one never can depend on its being twice alike. If a given radiator is sent to Professor Allen or to me or to some other person for a report on the heat radiation, we know the results would all be different. That being the case, I feel quite well satisfied to go on with the old formula and methods which I learned from Professor Allen of using K and the difference of temperatures.

JAMES A. DONNELLY: This paper of Professor Allen's is so voluminous and has covered so much more of the subject than has hitherto been covered that it seems absolutely hopeless to attempt to

discuss it in reasonable proportions in the confines of a single evening.

Some time ago in a paper on the time element in heating apparatus, the question came up for the temperature of the iron of the radiator; there seems to have been for a number of years an idea that the iron of the radiator was but little if any higher than the temperature of the room. And I am glad to see that Professor Allen has endorsed the stand that the iron in the radiator is very close to the temperature of the steam. In fact, I think that may be the reason it gives off radiant heat; if it were down to the temperature of the room, it might not give off any radiant heat.

One other thing that strikes me as very desirable at the present time, is the adoption of a particular size of radiator for all radiator tests, the general tables being constructed on a 38-in. type, two column, 10 section radiator. The statement does not seem to be made whether the particular size of radiator is adopted as a permanent standard. I think perhaps one of the things that might be added to this would be the advocacy of the adoption of some size radiator as a standard to which we could compare all others.

One other minor feature is that these tests are all apparently made on rated surface. It is rather a question whether, if we should ever change to actual surface rather than rated, it would be necessary to do much of this work over again. I hope not, because in all probability some day we are going to find actual surface specified.

I have attempted to add some lines to Fig. 4 on page 16 which show the variable transmission with a constant difference in temperature between the room and the radiator, because they have considerable application in figuring the variable amounts of radiation for different temperatures of room and for variations in outside temperatures. For instance, taking the point on the 40 deg. room temperature line, which corresponds to 185 deg. steam temperature, then a point on the 100 deg. room temperature line above the steam temperature of 245, and drawing a horizontal line, one can then read the different transmissions with a constant difference in temperature between room and steam. That has an application which shows, as Professor Allen pointed out, that as the steam temperature goes up the transmission increases, the difference between the steam and the room remaining the same. That means perhaps, that though the radiator gives off more heat, we have a greater heat loss due to air leakage, due to the higher temperature of the room. So that perhaps some of the constants I endeavored to determine some years ago as to variable amounts of radiating surface for different room temperatures might still apply.

The Author (J. R. Allen): I have made the assumption in all these tables that the actual surface and rated surface are the same. The experiments are based on actual surface, with that assumption. I know they are not always the same, but in many radiators they are almost the same.

With regard to Mr. Lockwood's statement, I do not agree with his viewpoint. I think the first thing to do is to get something to tie to. We want to do this first. There is no such thing as correct theory. There never was and there never will be. I will put it another way; we always speak of theory and practice. The only reason why theory and practice differ is because theory is wrong, that is all. Now no theory can ever take into consideration all the conditions of practice; therefore no theory is ever right. However, a theory is necessary in order to do business. First one must base his work on physical facts that are more or less fundamental. Now it is a question how many factors you put into your equation. We started out with one and I can now put in two factors. I admit this expression is not accurate. It may be within 5 per cent. If I wanted to make it accurate within 3 per cent I would probably have to put in two or three more factors. The question is where to stop.

However, I believe we ought to separate the two fundamental heat losses in a radiator, and not mix two things so different from each other as radiation and convection. If we wish greater refinement we can put in some more factors. I do not believe you will want to do that for some years. If you are accurate within 5 per cent, you are very accurate in the heating business. Did you ever think that heating engineers are far more accurate than almost any other kind of engineers in this country? We add about 50 per cent for the factor of ignorance. That is a mighty small quantity when you consider what the other engineers do. Take the structural engineer; he figures out the theory of the structure and he figures out the sizes and all his stresses, etc., and when he gets all through he says, "There is a factor of safety of 5"; and that knocks out 80 per cent of his theory in one blow. To his actual figures, as a matter of fact, he has to add 500 per cent. When we add 50 per cent we are 10 times more accurate than the structural engineer.

No. 542

A REPORT OF PROGRESS IN WARM AIR FURNACE TESTING AT THE UNIVERSITY OF ILLINOIS

A. C. WILLARD[1], URBANA, ILL.

Member

EXPLANATORY STATEMENT

SINCE it has been found impossible to arrange a conference between the members of the Sub-Committee on Furnace Testing, consisting of J. E. Emswiler, J. H. Kitchen, R. W. Noland, F. L. Pryor, and A. C. Willard, the following report has been prepared as a statement of recent progress in this field, rather than a Committee recommendation of procedure in furnace testing.

It should also be noted at the outset that this report is based on the data, results and testing methods employed in a special investigation of warm-air furnaces now in progress at the University of Illinois. This work is being conducted under a cooperative agreement between the *National Warm Air Heating and Ventilating Association* and the Engineering Experiment Station of the University. It involves the determination of the efficiencies and capacities of warm-air furnaces, and a study of the proper conditions of installation and operation so that furnaces may be accurately rated and properly selected to do the work required.

This investigation has been in active progress since October, 1918, and the equipment employed is located in the Mechanical Engineering Laboratory of the University, where the equivalent of a three-story house has been erected and equipped with a complete furnace heating system.

A permanent staff of at least three men is constantly employed on this work toward which the furnace manufacturers of the country contribute about $8,000 a year, in addition to the supervision, testing instruments and other facilities provided by the University. An illustrated report of progress, issued as Bulletin No. 112, has already been published by the Engineering Experiment Station.

[1] Professor of Heating and Ventilation, University of Illinois.

Report presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, January, 1920.

THE EQUIPMENT

The present testing equipment consists of the following:

(1) *Main Plant.* This plant (Figs. 1 and 2) consists of a complete recirculating gravity furnace system with typical leaders, stacks, and register which are carried by a three-story steel structure serving as the working skeleton of a house. The stacks are cased in to simulate furred wall conditions, and one of the four stacks to second floor as well as one of the two stacks to third floor is of single wall pipe. All other stacks are double wall with 5/16 in. air space. The recirculating duct takes air from the laboratory at about 70 deg. fahr. as the heating effect of the furnace is not appreciable in its effect on the temperature in the large laboratory in which the furnace plant is erected.

(2) *Auxiliary Plant.* A special single leader plant (Fig. 6) has also been set up with a 48 in. casing, heavily insulated, which is heated by a series of high pressure steam coils.

(3) *Calibrating Plant for Register Faces.* A separate calibrating plant (Fig. 3) for determining the true amount of air discharged at each register face on the main plant at the temperature used during any given test was erected at the same time as the main plant. A Pitot tube and piezometer ring in a 5-in. round section and special gage are used as standard for this calibration.

(4) *Calibrating Plant for Recirculating Inlet.* This plant is similar to (3) but operates on room air which is drawn through a return air opening duplicating the inlet opening on the furnace plant proper, and is used to get the true amount of air entering the furnace for any given test conditions. A Pitot tube and piezometer ring in a 10-in. round section and special gage are used as standard in this calibration. See also the Wahlen Gage shown in Fig. 13.

(5) *Heat Transmission Plant.* There has recently been erected a very simple equipment (Fig. 12) for studying the relative heat transmission of covered and uncovered tinned, galvanized and painted leader pipes.

CONDITIONS OF TESTING

(a) *General Program.* The conditions of testing are, of course, more or less dependent upon the objects in view in running these tests. The general program may be briefly summarized as follows:

(1) To determine the efficiency and capacity of commercial warm-air furnaces under conditions similar to those existing in actual installation with leaders, stacks and registers to form a complete system.

(2) To determine satisfactory and simple methods for rating furnaces so that the proper size and type of furnace can be definitely selected for the service required.

(3) To determine methods of increasing the efficiency and capacity of furnace heating equipment and the advantages or desirability of certain types of design.

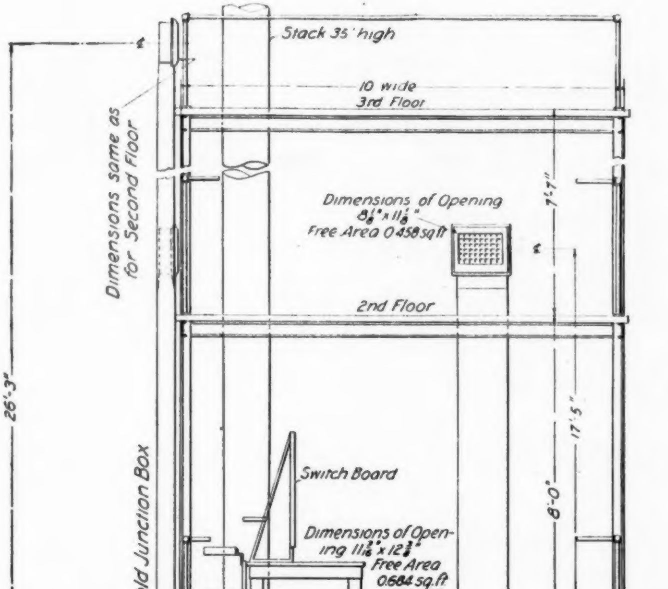
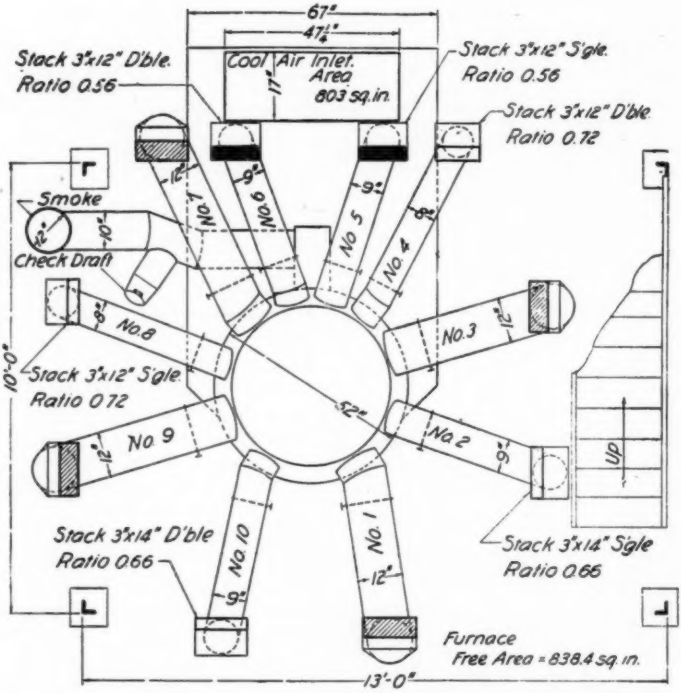


FIG. 1 SECTIONAL ELEVATION OF FURNACE TESTING PLANT.



	Leaders			Stacks		Registers	
	No.	Size	Area	Dimensions	Type	Dimensions	Free Area
1st Floor	1	12 in	113 sq. in	————	Asbestos Covered	$11\frac{3}{16}$ in x $12\frac{3}{8}$ in	0.684 sq ft
	3	12 in	113 sq. in	————		" "	"
	7	12 in	113 sq in	————		" "	"
	9	12 in	113 sq in.	————		" "	"
2nd Floor	2	9 in.	64 sq in	3 in x 14 in	S'gle	$8\frac{1}{8}$ in x $11\frac{1}{8}$ in	0.458 sq ft
	4	8 in.	50 sq. in	3 in x 12 in	D'ble	" "	"
	8	8 in	50 sq. in.	3 in. x 12 in.	S'gle	" "	"
	10	9 in	64 sq in	3 in x 14 in.	D'ble	" "	"
3rd Floor	5	9 in	64 sq. in	3 in. x 12 in	S'gle	" "	"
	6	9 in.	64 sq. in.	3 in x 12 in	D'ble	" "	"

Leader Area: 1st Fl. 452 sq. in., 2nd 228 sq. in., 3rd. 128 sq. in. Total 808 sq. in.

Percent Leader Area: 1st Fl. 55.9, 2nd 28.2, 3rd 15.8

FIG. 2. FLOOR PLAN AND DIMENSION TABLE OF FURNACE TESTING PLANT.

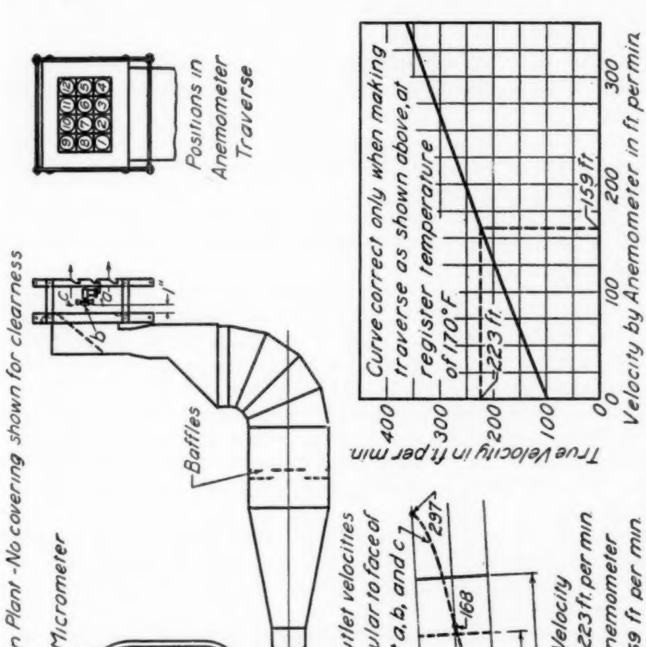


FIG. 3. SECTIONAL VIEW OF PLANT FOR CALIBRATING REGISTER OUTLET ANEMOMETER SHOWING DETAILS OF OPERATION

(4) To determine the heat losses in furnace heating systems and the value of insulating materials as affecting the economy of the furnace or the leaders and stacks, and finally of the system as a whole.
(5) To determine the proper sizes and proportions of leaders, stacks, and registers supplying air to first, second and third floors.
(6) To determine the friction losses in the cold air or recirculating ducts and registers and their proper size, proportions and arrangement or location.
(7) Eventually, to make a study and comparison of outside and inside air circulation as affecting the economy and operation of furnace systems.

(b) *Method of Running Tests.* It must be made very plain that the statement in paragraph (1) preceding, which calls for tests "under conditions similar to those existing in actual installations with leaders, stacks, and registers to form a complete system," imposes requirements which are most exacting if accurate and worthwhile data are to be obtained. Moreover, unless the data are secured under conditions which are truly representative of service conditions, their value to the furnace manufacturer, the installer and the engineer who attempts to design a furnace heating system is of little consequence.

The tests so far run, some of which are reported in this paper, have therefore been based on the following general considerations:
(1) Air supply—all recirculated under gravity flow at approximately 70 deg. fahr.
(2) Fuel—stove-size anthracite (soft coal will be used in later tests), with an ash content less than 14 per cent for dry coal.
(3) Firing period—tests start when first coal is fired (preliminary wood fire 10 per cent of coal capacity runs 15 minutes and is neglected) and are run until 80 per cent of original fuel charge (based on fuel pot capacity to a depth of 18 in.) is consumed. Coal is fired in three equal amounts; the first third, 15 minutes after wood fire is started, the second third in 15 minutes later, and the last third in the next 15 minutes. Fuel is not touched after this last firing with hard coal. At end of test, fire is quenched with water, drawn and ash pit cleaned. All residue above and below grates is weighed and its moisture content and heat value determined.
(4) Draft—must not exceed 0.2 in. water at any time.
(5) Equivalent register temperature—this is always taken as equal to the observed rise in temperature from inlet to register face added to 65 deg. fahr.
(6) Heat available in air at register face—is based on equivalent register temperature minus 70 deg. fahr.
(7) During any test the rise in temperature referred to in (5) is kept constant—thus if inlet increase 5 deg. fahr. during the test, the register temperatures are increased 5 deg. fahr. at the same time.

RESULT OF TESTS ON MAIN PLANT

Conditions Governing Tests. In the tests so far run to determine the efficiency and capacity of a warm air furnace when operating with a complete plant of leaders, stacks and registers under gravity air flow conditions, it has been very evident that the plant capacity as expressed in B.t.u. per square inch of leader pipe area, available

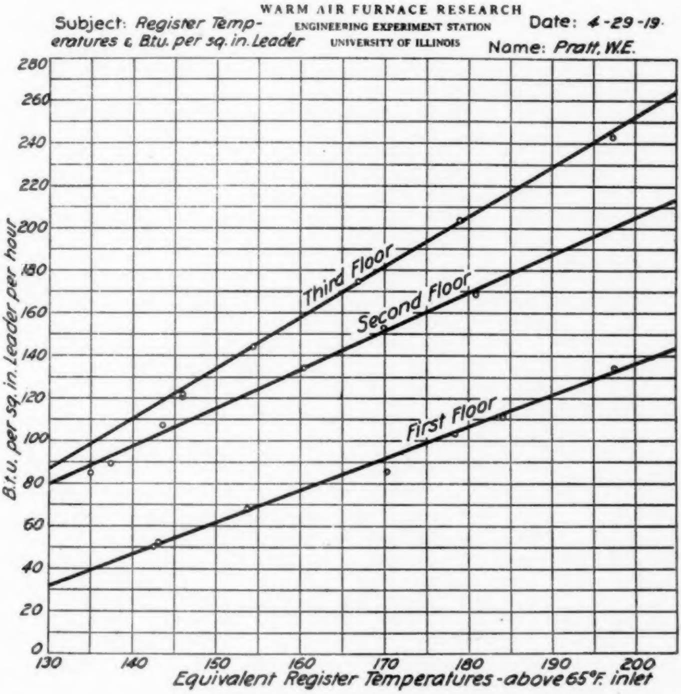


FIG. 4. CURVES SHOWING EFFECT OF REGISTER TEMPERATURE ON LEADER CAPACITY.

above 70 deg. fahr. at the register faces, varies greatly, increasing very rapidly as the register temperature increases. A series of seven tests was run to ascertain the magnitude of this increase in capacity for leaders supplying different floors, as well as to determine the capacity value of one square inch of leader area for either first, second or third floors. The results are given in Table 1 and in Fig. 4.

SIGNIFICANCE OF EFFECT OF REGISTER TEMPERATURE

On Leader Pipe Capacity and Furnace Rating. The first thing discovered from a survey of these data was that a square inch of

leader pipe area in a first floor leader has far less heating and air-carrying value than in a second or third floor leader as actually installed. In test No. 2 (*Aver. reg. temp.* 141.2 *deg. fahr.*), for example, a square inch of leader to first floor carries 50 B.t.u. per hour

TABLE 1. SUMMARY OF TESTS ON MAIN PLANT SHOWING EFFECT OF REGISTER TEMPERATURES ON CAPACITY OF FURNACE AND LEADERS.

WARM AIR FURNACE RESEARCH
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

Date 3-14 to 4-23-19
Name Entire Staff

Subject Summary of Seven Tests Showing Effect of Register Temperature on Capacity.

Fuel: Stove size anthracite, in solid fire pot. No draft over 0.2" of water.

Time	Test No.	1st	2nd.	3rd.	1st.	2nd.	3rd.	1st.	2nd.	3rd.	
		Average Temperature Rise and Register Temperature. †			Average Leader Vel. in ft. per min., and per cent Weight per floor.			Average B.t.u. Available for Heating above 70° per sq. in. Leader.			
1	2	3	4	5	6	7	8	9	10	11	12
3-14-19	1	78.2	70.0	81.0	118.5	215	264	52	85	121	
		143.2	135.0	146.0	39.6%	35.8%	24.6%				
Av. Reg. Temp.			141.4								
4-17-19	2	75.3	72.4	81.0	118.0	219	268	50	89	122	
		140.3	137.4	146.0	39.3%	36.2	24.4				
Av. Reg. Temp.			141.2								
4-23-19	3	88.8	78.6	89.5	131	226	274	68	107	144	
		153.8	143.6	154.5	41.9%	36.2	21.9				
Av. Reg. Temp.			149.8								
4-18-19	4	105.3	95.4	101.9	148	245	304	85	134	175	
		170.3	160.4	166.9	41.8%	34.9	23.3				
Av. Reg. Temp.			165.9								
4-21-19	5	113.5	105.0	114.0	159	252	315	103	153	204	
		178.5	170.0	179.0	42.8%	34.1	23.1				
Av. Reg. Temp.			175.8								
4-21-19	6	132.6	115.8	132.4	183	268	331	134	168	243	
		197.6	180.5	197.4	44.6%	33.0	22.4				
Av. Reg. Temp.			191.9								
4-21-19	7	119.3	105.3	114.1	165.5	224	246	68	107	144	
		184.3	170.3	179.1	47.6%	32.4	20.0				
Av. Reg. Temp.			177.9								
					Actual & Relative Leader Area						
					452 sq. in.	228	128				
					56.0%	28.2%	15.8%				

Remarks: All dampers wide open except in Test No. 7. For dimensions of leaders, stacks and registers, and plant layout see Fig. 2 and Table therewith.
† Register temperatures based on air entering furnace at 65° F.

available for heating above 70 deg. fahr., and for a third floor leader this value rises to 122 B.t.u. per hour, making *an increase* of 144 per cent. For the second floor the B.t.u. per sq. in. are 89, or *an increase* of 70 per cent.

A comparison of leader velocities for this same test shows 118 ft. per min. for the first floor, and 268 ft. per min. for the third floor, which is an increase of 127 per cent. For the second floor the increase in velocity is 85 per cent.

A still more significant discovery was made by comparing tests No. 2 (*Aver. reg. temp.* 141.2 *deg. fahr.*) and No. 6 (*Aver. reg. temp.* 191.9 *deg. fahr.*) from which it was found that a square inch of first floor leader has increased its capacity in available heating value above 70 deg. fahr. from 50 B.t.u. to 134 B.t.u. per hour, *a gain of* 170 *per cent.* For a second floor leader this value increased from 89 to 168 B.t.u. per hour or *a gain of* 89 *per cent,* and for a third floor leader this value jumps from 122 B.t.u. to 243 B.t.u. or *a gain of* 99 *per cent.* It should be noted that these gains are very large, much larger than the increase in velocities through these leaders.

If a comparison of velocities in the leaders for these same two tests is made, it is found that the first floor leader velocities have increased from 118 to 183 ft. per min., a gain of 55 per cent. In the case of second floor leaders, the velocities have increased from 219 to 268 ft. per min., a gain of 22 per cent, and for the third floor leaders the velocities show an increase of from 268 to 331 ft. per min., a gain of 24 per cent. Further comparisons of this kind at

TABLE 2. EFFECT OF DAMPERING SECOND AND THIRD FLOOR LEADERS TO INCREASE CAPACITY OF FIRST FLOOR LEADERS.

Test No.	Velocity, ft per min. 1st	2nd	3rd	B.t.u. per sq. in. 1st	2nd	3rd	Aver Reg. Temp.
5	159.0	252	315	103	153	204	175.8
7	165.5	224	246	111	137	160	177.9
Gain	6.5			8			
Reduction		28	31		16	44	

other register temperatures may be readily made by reference to the data in the table.

It should also be noted that the distribution of the air by weight to the various floors has changed with the increasing register temperatures. In Test No. 2 the relation was: *First floor* = 39.3 *per cent, second* = 36.2 *per cent and third* = 24.4 *per cent,* while in test No. 6 it changed to: *First floor* = 44.6 *per cent, second* = 32.4 *per cent and third* = 21.9 *per cent.* In test No. 7 (*Aver. reg. temp.* 177.9 *deg. fahr.*)an attempt was made to increase the velocity and heating value per square inch of leader pipe supplying the first floor by dampering the second and third floor leaders. This resulted in a distribution *of* 47.6 *per cent of the air to first floor,* 32.4 *per cent to second, and* 20 *per cent to third.* By reference to test No. 5 (*Aver. reg. temp.* 175.8 *deg. fahr.*) which is most nearly comparable, it will be seen that the gain in velocity (Table 2) and in B.t.u. per square inch of leader pipe to first floor was small and much more than offset by the reduction in these quantities for the second and third floors.

It is, therefore, quite evident that the practice of dampering leaders to upper floors as a result of poor design immediately cuts down the total capacity of a plant. The slight gain in heating effect on the first floor is accomplished at a serious sacrifice both in plant

capacity and efficiency. This problem is worthy of further investigation at the first opportunity.

The great significance of the data developed by these seven tests can hardly be overestimated and is the first important result of this

TABLE 3. SUMMARY OF FIVE COMPLETE PLANT TESTS FOR EFFICIENCY AND CAPACITY OF FURNACE

	UNCOVERED CASING			Lagged all over	Lagged above Middle Ring
ITEM	A-1	A-2	A-3	A-4	A-5
Date of test	4-23-19	4-30-19	5-1-19	5-3-19	5-9-19
Duration in hours	12.0	12.0	9.5	12.0	12.0
Ave. Temp. at Register Faces, deg. F. (actual)	169.4	182.5	197.7	188.3	175.4
Ave. Temp. at Register Faces, deg. F. (above 65 deg. F.)	149.8	167.5	186.1	168.8	167.0
Total weight of coal fired, lb.	256.0	255.0	255.0	255.0	255.0
Total weight of refuse out, lb.	141.5	107.3	108.5	112.5	114.5
Total equivalent coal in refuse, lb.	110.0	86.2	86.6	90.0	91.1
Total weight of coal burned, lb.	146.0	168.8	168.4	165.0	163.9
Rate of combustion, lbs. per sq. ft.	4.23	4.89	6.16	4.74	4.77
Average chimney draft, inches water	0.054	0.054	0.079	0.053	0.058
B.t.u. per lb. coal as received	12791	12791	12791	12791	12791
B.t.u. per lb. refuse at end of test	10023	10260	10200	10216	10180
Heat developed by coal burned per hr., B.t.u.	155,500	179,800	226,500	175,900	174,700
Ave. temp. of air at inlet, deg. F.	84.6	80.0	76.6	84.5	73.4
Ave. bonnet temp., deg. F. (actual)	181.5	194.8	210.7	200.2	188.0
Ave. temp. rise, inlet to bonnet, deg. F.	97.0	114.8	134.1	115.7	114.6
Ave. bonnet temp., deg. F. (above 65 deg. F.)	162.0	179.8	199.1	180.7	179.6
Cu. ft. air entering inlet per hr.	50,460	53,880	57,120	50,760	52,740
Wt. of air entering inlet per min., lb	60.15	65.00	68.30	60.30	64.20
Wt. of air leaving register per min. lb.	59.76	67.15	71.16	64.31	68.11
Heat put into air per hr. at bonnet, B.t.u.	84,200	107,500	132,000	100,500	106.000
Ave. temp. of flue gases, deg. F.	458	554	676	572	575
Overall efficiency* of furnace, per cent	54.20	59.70	58.20	57.20	60.66
Heat loss in dry flue gas, per cent.	8.82	10.62	12.98	10.85	11.46
Heat loss in water vapor, per cent.	4.30	3.89	4.16	4.00	4.06
Heat loss by radiation, and unaccounted for, per cent	32.68	25.79	25.66	27.95	23.82
Vel. in leaders, ft. per min. 1st floor (average)	131	148	167	145	144
Vel. in leaders, ft. per min., 2d floor (average)	226	252	271	257	261
Vel. in leaders, ft. per min., 3d floor (average)	274	307	332	275†	310
B.t.u. available per sq. in. leader, 1st floor (average)	67	91	120	89	89
B.t.u. available per sq. in. leader, 2d floor (average)	104	140	172	143	146
B.t.u. available per sq. in. leader, 3rd floor (average)	142	191	234	165†	192
Barometer, inches mercury	29.28	29.43	28.98	29.18	29.37

*These efficiencies are based upon weight of air as measured at inlet, and bonnet temperature corrected for radiation by the method already indicated. See Table 2.

† 3d floor leaders dampered.

investigation. It affects not only the basis for rating furnaces and designing furnace heating systems, but establishes very definite limits for rating and capacity tests.

Efficiency Tests. The results of five complete tests, on the main plant showing variations in efficiency with register temperatures,

are given in Table 3. A consideration of the results from the first three tests shows that the so-called radiation loss from the double casing and the bonnet of the furnace was high. If the first test No. A-1 is taken it appears that in a 12-hour run with an average equivalent register temperature of 149.8 deg. above a 65 deg fahr. inlet temperature, the heat put into the air passing through the furnace before it left the bonnet, amounted to 54 per cent of the total heat in the coal burned.

The heat carried away in the dry flue gases was 8.82 per cent and that lost in water vapor in the flue gases was 4.30 per cent, so

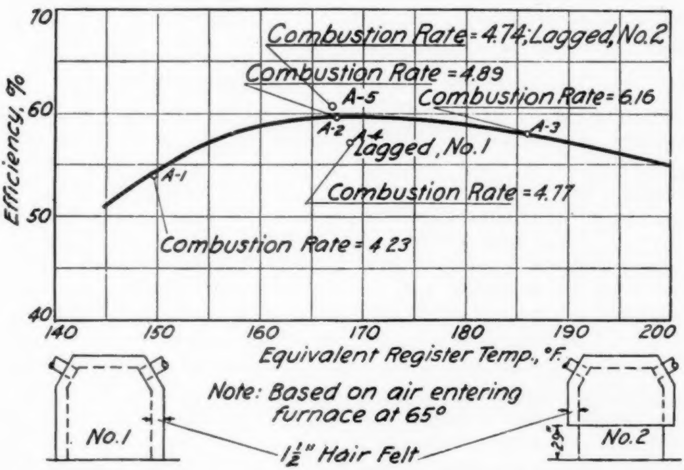


FIG. 5. EFFICIENCY CURVE FOR FURNACE, INSTALLED AS IN FIGS. 1 AND 2. OPERATING AT VARIOUS REGISTER TEMPERATURES AND RATES OF COMBUSTION

that only 67.32 per cent is accounted for. This means that over 32 per cent of the heat value of the coal burned was lost from the furnace casing and bonnet by radiation or in some unaccounted for manner.

Attention should be directed to the fact that in this test the actual weight of air entering the furnace as measured at the inlet was 60.15 lb. per min. The sum of the weights of air leaving the 10 register faces was 59.76 lb. or only 0.65 per cent less. In all tests, this agreement must be close or else the test must be rejected, as discussed later in this paper.

In order to determine the true significance of this radiation loss, a fourth test No. A-4 was run with the same register temperatures

as in No. A-2, but with a heavy layer of heat insulation material, consisting of 1½ in. of hair felt around the entire furnace and bonnet. The effect of this covering as well as the relation between efficiencies at various register temperatures is shown in the curves of Fig. 5. In addition to test No. A-4 a fifth test was run with the covering removed from the lower casing section of the furnace, and the results are tabulated and plotted as test No. A-5. No explanation is offered concerning these results until more data are available. It must be clearly understood that each of these tests must be checked by duplicate runs, which may affect the shape of the curves somewhat, but will not materially change their significance. In fact, this curve is so important that check tests should be run over the entire range of register temperatures from 120 to 190 deg. fahr. at intervals of not more than 10 deg. fahr.

RESULT OF TESTS ON AUXILIARY PLANT

In order to get some comparative data on the relative air-carrying capacity of warm-air stacks of varying shapes and with varying ratios of area as compared with the leader pipe supplying them, a special series of tests has been run on the auxiliary plant (Fig. 6) and the results reported in the table in this figure. The common practice of reducing a stack to 70 per cent of the area of a leader does not appear to decrease the air-carrying capacity materially below what is obtainable with a full size round stack of the same height.

EVAPORATIVE CAPACITY TESTS OF WATER PANS

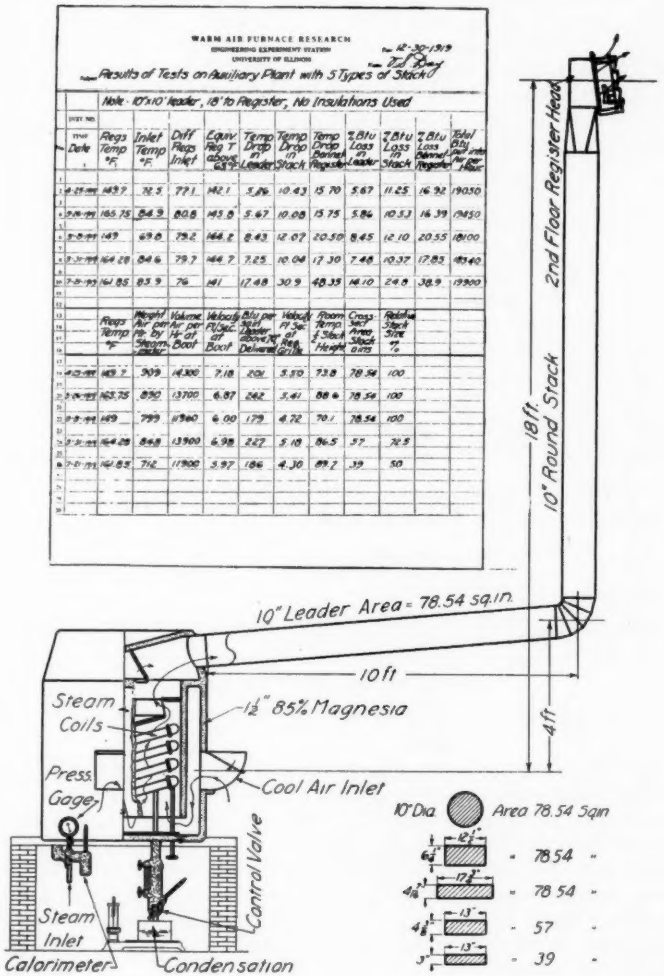
The evaporative capacity of water pans as used in furnace installation has been made the subject of special study by Mr. W. E. Pratt, formerly Research Associate, and some of the data obtained are submitted below, as these tests were also run on the main plant. The results apply to the three common types of pans, all of which were run successively in the furnace as shown in Fig. 7, when operating as a complete system (Fig. 1).

It will be noted that the dome pan is by far the most effective per square inch of surface, and that its total evaporation is greater than the crescent shaped pan around the fire pot up to the maximum temperatures used. The limited evaporation which takes place from the regular type of pan is too little to produce any appreciable effect, as is very well known to anyone who has ever attempted to determine the effect of such pans on the humidity of a heated house.

SPECIAL PROBLEMS ENCOUNTERED

There are two vital problems, which have made and will continue to make the testing of a gravity warm-air furnace heating system a most difficult and elusive undertaking. These two problems have already involved a great deal of research work and up to the present have represented the principal work of this investigation.

The Problem of Temperature Measurement. The first problem



WARM AIR FURNACE RESEARCH
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

12-30-1919

Results of Tests on Auxiliary Plant with 5 Types of Stack

Note - 10"x10" leader, 18' to Register, No Insulations Used

Date	Regs Temp °F.	Inlet Temp °F.	Diff Regs Inlet	Equiv Reg T above 65°F	Temp Drop in Leader	Temp Drop in Stack	Temp Drop Bonnet Register	% Btu Loss in Leader	% Btu Loss in Stack	% Btu Loss Bonnet Register	Total Btu per min Air per Hour
4-25-19	143.7	72.5	77.1	142.1	5.26	10.43	15.70	5.67	11.25	16.92	19050
5-26-19	165.75	84.9	80.8	145.8	5.67	10.08	15.75	5.86	10.53	16.39	19850
5-8-19	149	69.8	79.2	144.2	8.43	12.07	20.50	8.45	12.10	20.55	18100
5-31-19	164.28	84.6	79.7	144.7	7.25	10.04	17.30	7.48	10.37	17.85	19340
7-21-19	161.85	85.9	76	141	17.48	30.9	48.35	14.10	24.8	38.9	19900

	Regs Temp °F	Weight Air per Hr. by Steam-meter	Volume Air per Hr at Boot	Velocity Ft/Sec. at Boot	Btu per Sq in Leader above 70° Delivered	Velocity Ft Sec at Reg. Grille	Room Temp. & Stack Height	Cross-Sect Area Stack sq ins	Relative Stack Size %
4-25-19	143.7	909	14300	7.18	201	5.50	73.8	78.54	100
5-26-19	165.75	850	13700	6.87	242	5.41	88.4	78.54	100
5-8-19	149	799	11960	6.00	179	4.72	70.1	78.54	100
5-31-19	164.28	848	13900	6.98	227	5.18	86.5	57	72.5
7-21-19	161.85	712	11900	5.97	186	4.30	89.2	39	50

FIG. 6 AUXILIARY, SINGLE-LEADER PLANT FOR TESTING LEADERS, AND STACKS.

deals with the measurement of the temperature of air flowing through the ducts, casing, leaders and stacks of a furnace system. Thermocouples have, of course, been used in this work, the copper-constantan combination having been found quite satisfactory where so many temperatures must be read (Fig. 8). However, attempts to get the correct air temperatures in the furnace bonnet, or rise in temperature through casing, have made it necessary to make a special study of radiation effects when the hot junction of couple is exposed in any way to hot furnace castings. This whole question of air temperature measurement has been in charge of Prof. A. P. Kratz

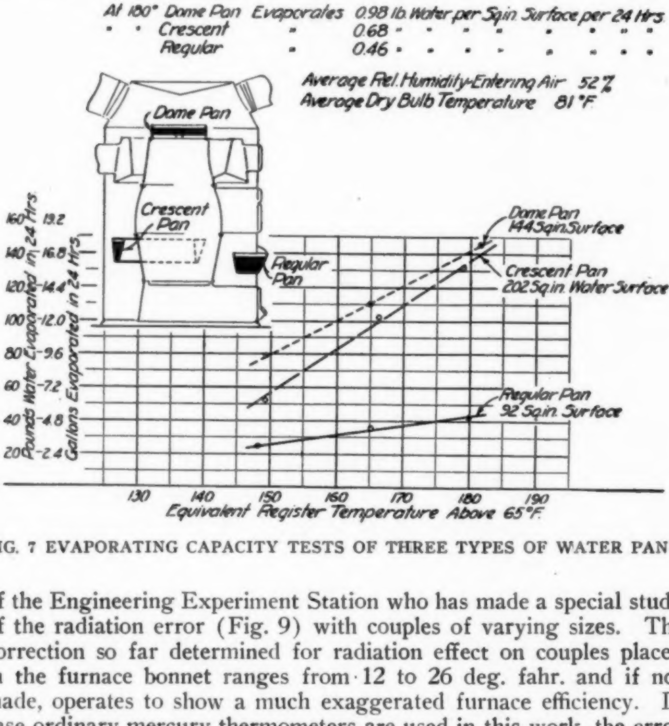


FIG. 7 EVAPORATING CAPACITY TESTS OF THREE TYPES OF WATER PANS.

of the Engineering Experiment Station who has made a special study of the radiation error (Fig. 9) with couples of varying sizes. The correction so far determined for radiation effect on couples placed in the furnace bonnet ranges from 12 to 26 deg. fahr. and if not made, operates to show a much exaggerated furnace efficiency. In case ordinary mercury thermometers are used in this work, the error becomes much larger than here indicated. The magnitude of this error can, in the case of the bonnet couples, be also determined in the following manner:

A typical leader located in same position as leader No. 2, Fig. 2, but 12 in. in diameter was lagged between the bonnet and the boot with 2 in. of hair felt, and a series of readings of the temperatures taken at the two points. The hair felt was then removed and a second series of temperature readings taken. In case the reading of

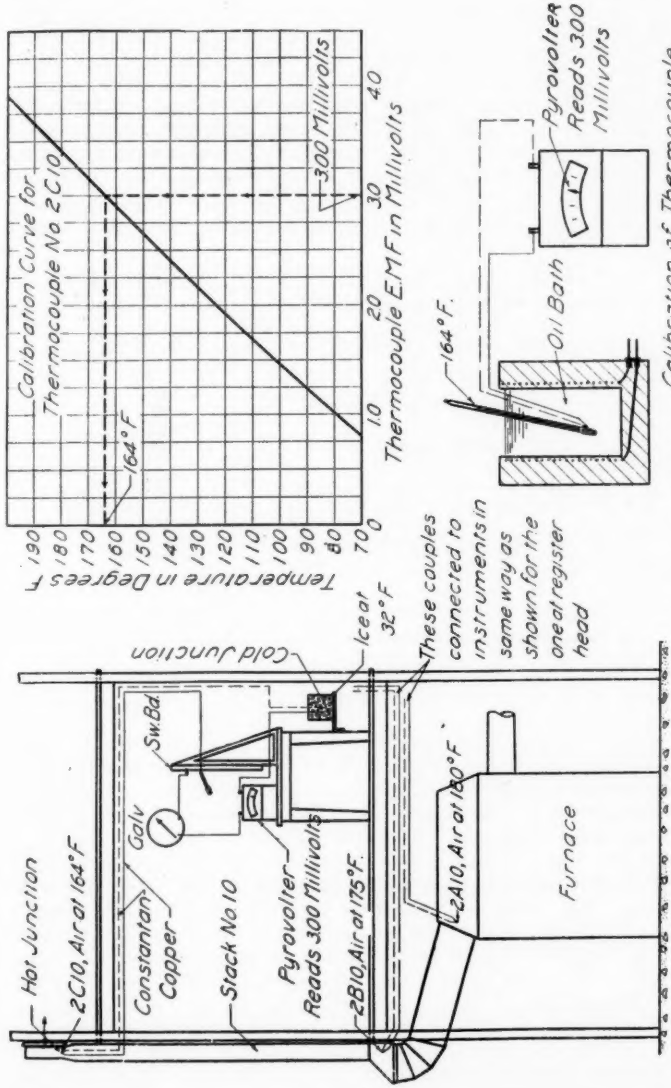


FIG. 8. DIAGRAM OF TEMPERATURE MEASURING SYSTEM, SHOWING METHOD OF USING AND CALIBRATING THERMOCOUPLES.

the thermocouple in the bonnet had not been affected by radiation, the reading of this couple and the one in the boot with covered leader, should have been very nearly the same, since there was practically no heat loss between the two points. The difference shown in the test was 28 deg. fahr. This difference was attributed to the radiation effect of the hot surfaces on the couple at the bonnet. As the air probably lost some heat between bonnet and boot, although the leader was covered, this difference should have been reduced one or possibly two degrees in estimating the radiation effect. It is certainly as great as 28 — 2 = 26 deg. and probably amounted to 27 deg. fahr. in the preceding case. The uncovered leader showed a loss of 33 deg. fahr. by the subtraction of the read-

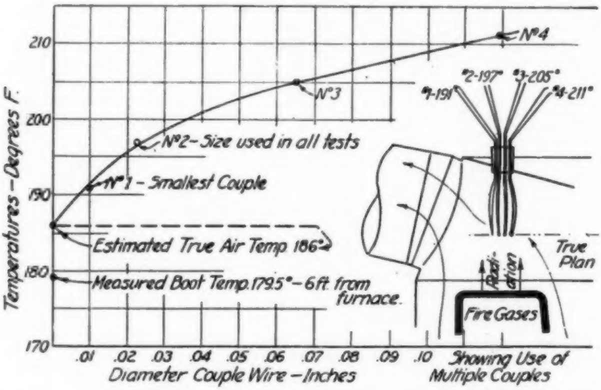


FIG. 9. SAMPLE RADIATION TESTS TO FIND TRUE AIR TEMPERATURE AT BONNET.

ings of the couples at the bonnet and boot. Deducting the 26 deg. fahr., attributed to radiation effect on the couple at the bonnet from this difference in temperature, gives 7 deg. fahr., as the approximate loss between bonnet and boot in the 4 ft., of uncovered 12-in. leader pipe with an air velocity of 131 ft. per min. in the leader.

The results from these tests are particularly significant because they show that while the correction for each bonnet thermocouple varies with the position of the hot junction of these couples, we can arrive at a fairly correct bonnet temperature by adding the temperature drop along each leader to the boot temperature. This latter temperature is taken so far from the bonnet, and at such a location that any radiation effect is practically negligible.

Temperature Variation Across an Air Stream. There is still another aspect to this measurement of the temperature of a flowing stream of air which has been given a great deal of study by Mr. V. S. Day, research assistant. It is a well known fact that there is

a great variation in temperature across any section of an air stream whether the air current is flowing in a nearly horizontal leader or in a vertical stack. The exact location of the thermocouple in such a stream is a matter of vital importance, especially if this reading is to be compared with another reading further along the stack or leader. As a preliminary study with rather crude apparatus showed a surprising variation in an ordinary leader, it was decided to go into the matter more thoroughly and a special temperature searching tube under micrometer control was developed and put into operation with great success. A few sample curves are submitted (Fig. 10) which speak for themselves. Both temperature traverses were made

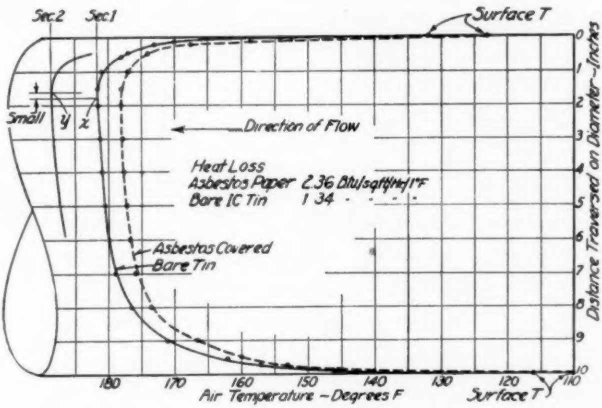


FIG. 10. TEMPERATURE TRAVERSE OF 10 IN. LEADER.

in the same 10-in. pipe just 5 ft. from bonnet on the auxiliary plant (Fig. 6) and at the same section taken along a vertical diameter. The bonnet and room temperatures were the same in both cases, and hence the curves are a direct index of the increased heat and air carrying capacity of a bright tin leader pipe as compared with the same pipe covered with one layer of asbestos paper, weighing 10 lb. to the 100 sq. ft.

From an inspection of the curves it is apparent that in the case of the bright tin leader, the maximum air temperature at the section is 181.5 deg. fahr. at a point 2 in. below top of pipe. These temperatures fall off rapidly to 154 deg. fahr. at a distance 0.01 in. inside of top of pipe, while the temperature of the metal surface itself (by thermocouple soldered to outside of leader) is 132 deg. fahr. Below the center of the pipe the air temperatures also fall off rapidly to 130 deg. fahr. at a distance 0.01 in. inside of bottom of pipe, while the metal surface here is at a temperature of 116 deg. fahr. The temperature curve for the asbestos covered pipe is

similar, but while its maximum is 178 deg. fahr. at 2 in. below top of pipe or 3.5 deg. fahr. less than in a bright tin leader at the same position, the metal surface at top and bottom of leader is nearly 9 deg. fahr. less at the top and 6 deg. fahr. less at the bottom than the metal surface of the uncovered leader. *The asbestos paper covered pipe is losing heat more rapidly than the bright tin leader pipe.*

It therefore becomes a nice question to determine the heat content of the air at any given section and compare it with the heat content at some other section. This problem is still further complicated by the fact that a velocity traverse at this same section (Fig. 11) with a Pitot tube and micromanometer shows a somewhat similar variation in uniformity of flow across the section. The true mass

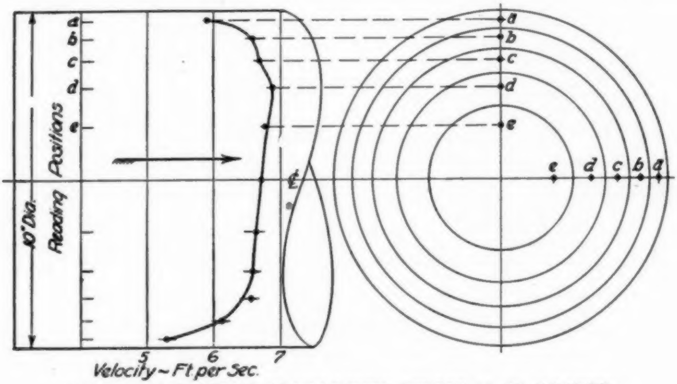


FIG. 11 VARIATION IN VELOCITY ACROSS 10 IN. LEADER.

temperature is then the summation of the products of the weights of air at each concentric equal area (a, b, c, d, and e) by the mean temperature at that concentric area (Fig. 11), divided by the total weight of air flowing.

So long as the temperature traverse curve at one section has the same shape as at another section, and the velocity traverse curves are similar to each other, *differences in temperature and heat content* are quite correctly obtained if the thermocouples are located at similar points as indicated by the temperature curves at the two sections. See (x) and (y) at two sections on Fig. 10.

Heat Loss from Covered and Uncovered Leaders. Reference has already been made to the fact that covering a bright tin leader with a single layer of asbestos paper apparently increases the heat loss from the leader. This appears to be due to the higher coefficient of radiation of asbestos paper as compared with a polished metal surface, and also to the increased surface area of the asbestos covering. This at once brings up the special problem of relative

values of insulation methods in *this particular field where thin bright tin pipes are used.* In order to secure some corroborative data along this line, a special heat transmission plant (Fig. 12) supplied with low-pressure steam has been set up by Mr. Day and a few of the more interesting results are given in Table 4. In each case, a number of duplicate runs of at least 10 hours' duration have been made. In all tests reported the drums are of the same size and show no appreciable collection of air, as the outlet thermometers at end of test always check with the steam temperatures within a degree or two. Five drums are run at one time and No. 1 drum is always run as a control.

TABLE 4. RELATIVE HEAT LOSSES FROM THIN SHEET METAL PIPES WHEN COVERED AND UNCOVERED.

	Description of Drum	Wt Steam Condensed in 10 Hrs	Coef.* of Emissivity Btu/hr/ft²/1°F
1	Bright IC Tin, 1 Leader Section	11.63	1.40
2	Same as No. 1 but covered with one sheet 10 Lb Asbestos Paper	17.80	2.30
3	Same as No. 2 but Painted with Gray Enamel	18.14	2.32
4	Same as No. 1 but Painted with Gray Enamel, as in No. 3 case.	18.88	2.40
5	Black Iron No. 28 U.S. Gage	18.29	2.25
6	Galvanized Iron No. 28 Gage	11.72	1.55
7	Same as No. 1 but Covered with 3 Ply Air-cell Asbestos Paper	5.86	.70
8	Same as No. 1, with 5/8" Air Space Made by double Wall of Tin	6.32	.78

*Coef based on temp difference Steam to Air

An attempt has been made to connect the data tabulated in Table 4 with the temperature loss found to occur in the case of the air flowing in the 10-in. leader for which the temperature traverse curves have been given. If we assume this loss in temperature is equivalent to the heat given off from the surface of the leader, which of course is undoubtedly true, we can calculate coefficients of emissivity for the bright tin and also for the asbestos-covered tin, using metal surface temperatures as read by thermocouples, and already plotted in Fig. 9. These calculated coefficients based on a 10 ft. run of leader for conditions shown in curves give values of 1.34 B.t.u. for bare tin and 2.36 B.t.u. for asbestos covered tin, similar to conditions No. 1 and No. 2, respectively, in Table 4.

The Problem of Air Velocity Measurement. There are two possible methods of determining the amount of air actually flowing in through the inlet and out through the leaders and stacks of a warm-air furnace heating plant.

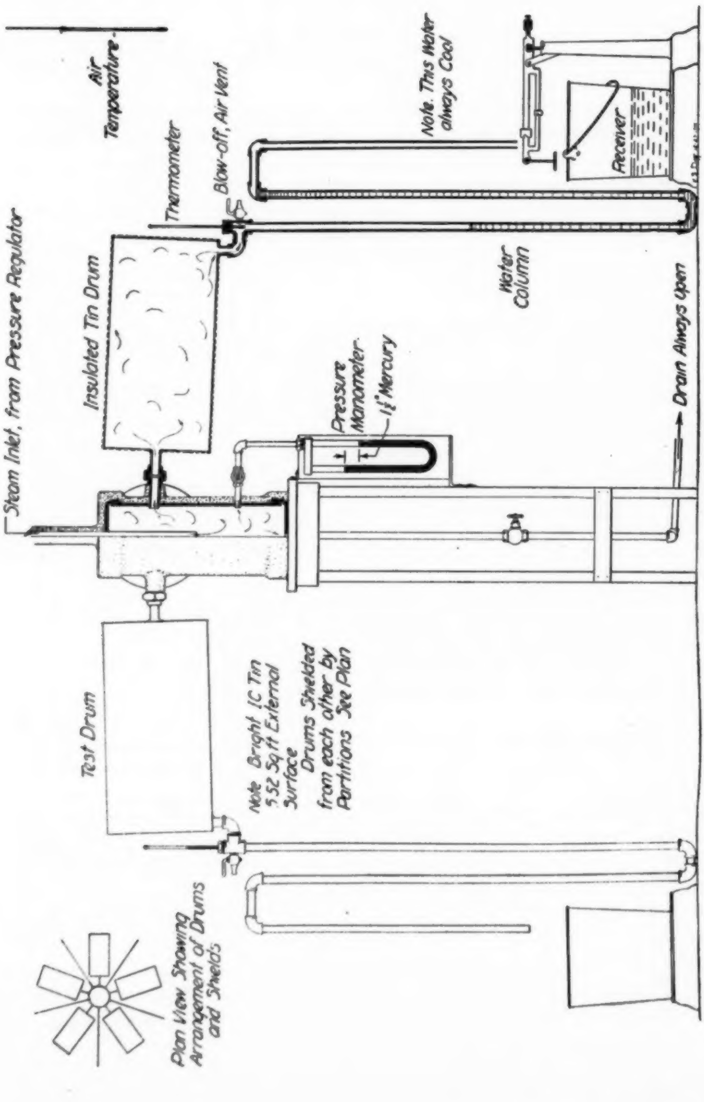


FIG. 12. INSULATION TESTING PLANT.

The first, and most obvious method, would be to attempt to measure the velocities directly, using a Pitot tube and a sensitive gage. This has been attempted and a very sensitive and accurate gage (Fig. 13) reading to 0.0001 in. of alcohol, has been developed by Mr. F. G. Wahlen, research graduate assistant. When it is remembered that the actual velocities range from as low as 2 ft. to a maximum of seldom over 5 ft. per second in these systems, it will be apparent that no ordinary differential gage will be of the least

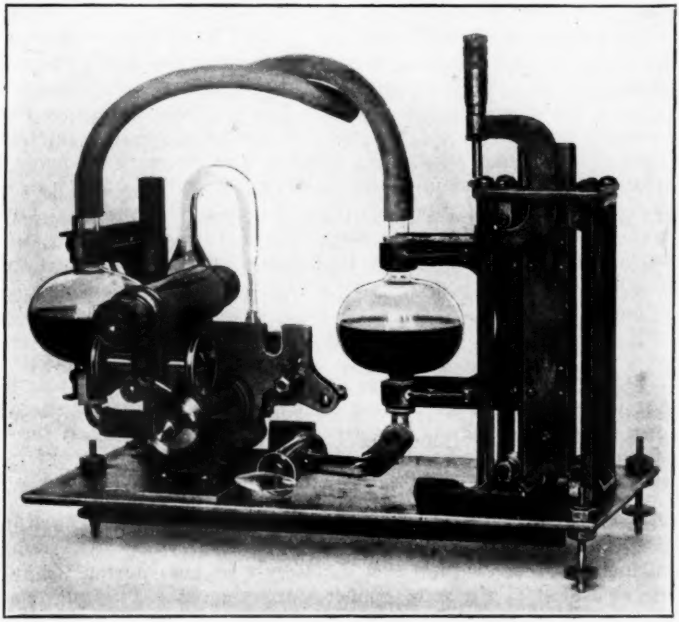


FIG. 13. THE WAHLEN GAGE, SENSITIVE AND ACCURATE TO 0.0001 IN. ALCOHOL.

value in making direct measurement. Moreover since a painstaking traverse is always necessary, the above scheme fails absolutely when applied to an extensive plant where many readings must be taken simultaneously. It is, however, of great value in studying single leader and stack systems.

The second method which may be used is to employ a simple "field" instrument which may be used quickly, is simple in construction and easily replaced. Such an instrument must, of course, be accurately calibrated and frequently checked; and as already indicated, this is the method which has been in use in this investigation from the start. It is the unanimous opinion of the men on

the staff that this method is the only workable one, and that its only limitation is the inaccuracy of the Pitot tube or orifice used in its calibration. Reference to Table 3 will show the practical results obtainable with this scheme of measurement, using calibrated anemometers, run against Pitot tubes and the Wahlen gage (Fig. 13). This gage was found absolutely essential in this calibration work. *In test 1-A, the weight of air entering inlet per minute was 60.15 lb. and the sum of the weights of air leaving ten outlet register faces in the same time was 59.75 lb., or a discrepancy of 0.65 per cent. In test A- 4 the results are not as good, since the weights in and out fail to check by 64.31 — 60.30 = 4.01 lb. or a discrepancy of 6.6 per cent. This discrepancy can be cut down one-half by assuming the true weight is the mean of the inlet and outlet weights.* We have not only done this, but are going to make a painstaking attempt to get still greater accuracy in the calibration of our anemometers. In other words, an attempt will be made to make a fundamental measurement of air that is more accurate than can be made by either Pitot tube or orifice, which methods, it has been found, do not check each other when placed in the same line by from 5 to 10 per cent. It is quite out of place, however, to discuss this new scheme here.

SIGNIFICANT CONCLUSIONS

1. The successful testing of a warm-air furnace is so tied up with the testing of the furnace heating system as a whole, that to attempt to test the furnace without the plant is of little or no value, if rating or capacity data as well as thermal efficiency and economic performance data are desired.

2. No furnace testing data have any real value until the investigator can demonstrate that his methods of air measurement are fundamentally correct, and that the weight of air entering the furnace measured at the inlet temperature is equal to the aggregate weight of air leaving the furnace measured at the various outlet temperatures.

3. Warm-air furnace testing also involves unusually complete and accurate methods for measuring true air temperature, where radiation and stream line effects must always be corrected for in getting these temperature data. Most absurd results may be obtained if this is not done.

4. Furnace test procedure as to method of handling the fire and computation of results is of secondary importance and should be worked out to accord as nearly as possible with the steam heating boiler code.

5. A warm-air furnace test is a question of true air-velocity and true air-temperature measurement and nothing else, as all other problems become insignificant when compared with these two.

No. 543

REPORT ON STATUS OF SCHOOL VENTILATION IN THE UNITED STATES

AT the Semi-Annual Meeting of 1919, an interesting discussion followed the presentation of the paper entitled, "A Comparative Study of Natural and Mechanical Ventilation for School Rooms," by Legg and Walker, in which the suggestion was offered that a resume of the paper be submitted to the various Boards of Education throughout the country, with the idea of learning their experiences in connection with mechanical forms of ventilation. In accordance therewith a three page resume, containing the principal conclusions that were brought out in the paper, was prepared and sent out to the school boards of 224 cities in the United States, the population of which amounted to 25,000 inhabitants or over. To this communication there have been a number of interesting responses, totalling 22, and the indications from these were so pronounced as to justify the expectation that a greater volume of responses might show the same general average.

The questionnaire consisted of a resume of tests conducted in the James Burrill Angell school in Detroit, Mich., and a letter inquiring whether the results in the schools of the city addressed, agreed with the results of these tests. The resume read as follows:

RESULTS OF TESTS
COMPARING MECHANICAL AND NATURAL VENTILATION OF SCHOOL ROOMS

In February, 1919, a series of tests was instituted in a Detroit public school "to determine what qualities must be present in class rooms so that the physical well-being, comfort and mental alacrity of the pupils may be at as high a standard as possible, and thereby render the pupil completely at ease and readily responsive to the efforts and influence of the teacher." To that end, comparative studies were made of mechanical and natural (window) ventilation.

The James Burrill Angell school, a 20-room, two-story building situated in one of the better residence districts of the city, was selected for the test. The mechanical equipment of the building consisted of (1) a certain amount of direct radiation in each class room, sufficient to care for 60 per cent of the heat losses of the room; (2) a plenum system of ventilation whereby air drawn from above the roof is washed, tempered and humidified, in-

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, at New York, N. Y., January, 1920.

troduced into the room through supply registers near the ceiling of the inside wall and exhausted by gravity through registers in the same wall at the floor line. The control apparatus was set to maintain a uniform temperature of 68 deg. fahr. in the class room and a relative humidity of approximately 42 per cent.

For the tests, 16 typical rooms were selected, eight of which were operated with the regular mechanical ventilation provided by the school equipment. The remaining eight had all ventilation openings blocked off and depended for ventilation solely upon wide-open windows, in accordance with the practices advocated in some cities. The rooms chosen were so located that they had the same exposure and so that a mechanically-ventilated room was directly above a naturally-ventilated room, and vice versa.

In the naturally-ventilated rooms, extra radiation under thermostatic control was installed in front of the windows, which were screened with fine-mesh cheese-cloth to break the wind and keep out the dust, and draft deflectors were also installed to protect scholars, nearest the windows, from drafts.

It was the intention to collect and classify information upon the following points:

1. Temperature—Dry and wet bulb; to be the average of four selected stations in each room taken daily;
2. Air Motion—Daily readings at each of four stations in a room;
3. Primary sense impression—To be the observer's impression upon entering the room. Recorded as "hot," "close," "pleasant" or "cool."
4. Determination of CO_2—To be made at each station for purposes of determining (a) the total amount of air supplied and (b) the distribution of air within the room;
5. Dust count—To be made at each station; determination made with Hill's dust counter.
6. Bacteria count—To be made at each station by exposing standard Agar plates two minutes and incubating 24 hours at 20 deg. cent.;
7. Determination of fuel consumption—To be made by measuring condensation from all radiation and from radiation in naturally-ventilated rooms;
8. Determination of mental alacrity of pupils—By means of comparative mental tests similar to the Binét test;
9. Comparison of physical condition of pupils—By careful medical inspection and constant nursing supervision.

It was proposed that these studies should extend over an entire school year but an unforeseen element, the nature of which is explained later, entered into the calculations and prevented the accomplishment of this intention. Because of the short duration of the test, sufficient data to warrant their presentation were gathered on only a few of the points under consideration. The following is a summary of such data:

In the rooms with natural (window) ventilation, the *dry bulb temperature* varied sharply from 70 deg. to 82 deg., the *wet bulb temperature* from 49 deg. to 56 deg., and the *sense impression* fluctuated between the extremes of "hot" and "cool," seldom touching the mean of "pleasant."

In the mechanically-ventilated rooms, the *dry bulb temperature* was almost constant at about 70 deg. and the *wet bulb temperature* hovered consistently around 55 deg. The *sense impression* was uniformly "pleasant," not varying at all.

The *sense impression* in the naturally-ventilated rooms showed a definite and striking relation to the wind, whereas in the mechanically-ventilated rooms, it was not thus affected.

The factor which necessitated the discontinuation of the tests was a feeling of dissatisfaction that developed in connection with the conditions that were obtained in the naturally-ventilated rooms. Whereas, in the beginning the attitude of the teachers had been most favorable and they had shown great eagerness to be assigned to the naturally-ventilated rooms, before the ob-

servations had been carried on for two months, a strong opposition arose which spread to the children and thence to the parents, making it impossible to further conduct the experiment upon an unbiased basis. The contentions of the opposition were as follows:

a. It was impossible to keep the temperature and air motion conditions in the naturally-ventilated rooms within the bounds of comfort.

b. The absence, because of illness of pupils and teachers in naturally-ventilated rooms, increased to an alarming extent.

c. The air in the naturally-ventilated rooms was stagnant and heavy, causing depression and headaches.

Of the 22 answers received, 20 were in favor of mechanical ventilation, one (a southern state), did not favor it, and one favored a combination of mechanical and natural ventilation. The results are shown in Table 1.

TABLE 1. TABULATION OF REPLIES FROM BOARDS OF EDUCATION

Favorable to Mechanical Ventilation	Unfavorable to Mechanical Ventilation	Favor Combination of Mechanical and Natural
Erie, Pa.	Athens, Ga.	Lincoln, Neb.
Portland, Ore.		
Pittsburgh, Pa.		
New York, N. Y.		
Youngstown, Ohio		
Everett, Mass.		
Decatur, Ill.		
Binghamton, N. Y.		
Seattle, Wash.		
St. Louis, Mo.		
Salt Lake City, Utah		
Boston, Mass.		
Newton, Mass		
Rochester, N. Y.		
Davenport, Ia.		
Elmira, N. Y.		
Newburgh, N. Y.		
New Rochelle, N. Y.		
Hartford, Conn.		
Watertown, N. Y.		

With few exceptions, it was very evident that, even from the schools that favored mechanical ventilation, few authentic data were to be obtained. Their reasons for preferring the mechanical ventilation were based almost exclusively upon "sense impression." No tests had been made and no records kept. Exceptions to this rule were Lincoln, Neb., Pittsburgh, Pa., and New York, N. Y.

Lincoln, Neb., sent a report by Dr. Katherine H. K. Wolfe, supervisor of hygiene in the Lincoln schools, claiming that a combination of window ventilation and mechanical is the desirable method and that, where a choice between natural ventilation and closed window mechanical ventilation must be made, better health results are secured with the natural ventilation. Certain tests are quoted, among them the following:

"A principal in charge of a recently remodeled fourteen room school building equipped with a plenum ventilation system, similar to the one used for the tests in Detroit, except that it has no air washer, has demonstrated this fall that it is possible to combine window ventilation with even this system. The principal and most of her teachers possess the "fresh air habit." Pupil health committees assumed responsibility for class room ventilation in ten rooms. In the ventilation of this building it was assumed that a smaller continuous supply of fresh out-door air in a class room is preferable, from the sanitary standpoint, to a larger supply at long intervals plus the possibility of not obtaining it through neglect.

"At no time has the temperature in any occupied class room in this building been found as high as 72 degrees by the inspector, during frequent visits. The temperature in the different rooms in this building usually ranged from 66 to 69 degrees.

"The per cent of attendance in this building this fall, ranked the highest of all buildings in the Lincoln system.

"The consumption of fuel was no greater than in another recently remodeled building, equipped with mechanical ventilation, where the windows were kept closed, higher temperatures prevailed, and where the per cent of attendance was the third from the lowest in the school system."

Pittsburgh, Pa., takes a very strong stand for mechanical ventilation and summarizes its advantages, as

1. Positive compliance with state school code requirements of 30 cu. ft. per min. of fresh warmed air per pupil;
2. More accurate temperature and humidity control;
3. Absence of objectionable draughts;
4. Fuel saving due to lower room temperature possible when proper relative humidity is maintained.
5. Sensibly greater comfort and increased efficiency of pupils;
6. Decrease in respiratory diseases.

In New York, N. Y., owing to operating and maintenance conditions that left much to be desired, mechanical ventilation has not received as full a test as is desirable. However, Mr. F. G. McCann, chief of the heating and ventilating division of the Bureau of Construction and Maintenance, offers the following comments that are of interest:

In years past, under normal conditions, many of our mechanically ventilated plants, run by intelligent and conscientious janitor-engineers, showed excellent conditions and teachers and principals not only were satisfied but actually demanded that mechanical ventilation be provided during the colder months.

Some years ago a careful survey was made by Dr. Luther Gulick of the Sage Foundation, as to relative effects of the various systems of ventilation on pupils of our schools, as shown by promotions, etc., and this showed a markedly higher rate of promotions in mechanically-ventilated schools than

in gravity or open window ventilated schools. This was by averages of all the schools in a class, being for one hundred or more buildings in each class, and not making any allowance for antiquated installations. It is believed that a comparison based on properly equipped and properly operated schools would show even more clearly, the advantages of mechanical ventilation.

The tests made in our schools by the Department of Health of this city and reported by Dr. S. Josephine Baker of that Board in February, 1918, were carried on under conditions which render them of little value except as evidence of improper conditions, shown thereby to exist under present methods of control.

No attempt was made in such tests to confine the study to modern schools, equipped with well-designed and well-operated plenum installations, as compared with modern schools having only window ventilation. The schools selected were of all types and ages and no special supervision of operation was given, hence so many variable factors enter into the causation of the noted readings that it is impossible to deduce therefrom any reliable data of the effects of plenum ventilation as compared with window ventilation.

As an endeavor to better conditions by unifying control of design, installation, maintenance, operation and fuel supply, heretofore handled in separate and largely unrelated bureaus, our Board of Education has recently appointed a Superintendent of Plant Operation, who will in the near future have control of all of the above matters, thus making better control and assuring better operating conditions. Much is hoped from this change.

Also, for the buildings now under construction and for those designed by us some years past, we have arranged the equipment so that the auditoriums, the playrooms and gymnasiums, and the classrooms, may be separately heated and ventilated, in order that it may be unnecessary to heat or ventilate unoccupied portions of the buildings. This makes it more certain that ventilation will be provided as needed, especially outside of regular school sessions, and effects economy of operation.

When economic, and especially fuel, conditions become more normal again, we expect to be able to greatly improve conditions of ventilation in our buildings, but under the conditions heretofore existing (to correct which frequent abortive attempts have been made), there is no question but that the ventilation in our schools left much to be desired, largely due to operating and maintenance conditions beyond our control.

In view of the national interest which this question has assumed, a statement recently made by Mr. Frank Irving Cooper, member of the Society, in the November, 1919, issue of the *School Board Journal,* is here, with his permission, presented in abstract:

One of the first studies of the Committee on Standardization of Schoolhouse Planning seemed to show that 5 per cent of total area of schoolhouses should be the normal for the ventilating ducts. These were the ducts for delivering the fresh warmed air to schoolrooms and the ducts for carrying away the vitiated air from these same rooms. This normal was decided upon after a considerable number of school buildings had been investigated and the results compared with the known requirements of states whose school planning regulations had been tabulated in 1915. Thirteen of these states required 1800 cu. ft. of air provided per person per hour. The State of Wisconsin made the exception by requiring 1200 cu. ft. per person per hour. Two states, Massachusetts and Minnesota, required this air to be delivered at the register at a speed not to exceed 300 ft. per minute which has been generally accepted as correct by heating engineers.

These data would seem to require a fairly constant flue area dependent upon whether the propulsion for the air was a gravity or positive system. The State of Indiana takes cognizance of this difference by requiring a proportion of sixteen inches flue area for a gravity system as against ten square inches for a fan or positive system.

TABLE 2.[1] VARIATIONS IN STATE REQUIREMENTS FOR SCHOOLROOM VENTILATION

	Required cu. ft. per hr.	Required size of duct 10 sq. in. gravity, 16 sq. in.	Air velocity not to exceed per min. at outlet	Existing per cent area of ducts to entire building	Tabulation number
Indiana	1800	..	..	1.67	1
Louisiana	1800	..	..	..	..
Massachusetts	1800	..	300	5.91	59
Massachusetts	1800	..	300	5.63	54
Massachusetts	1800	..	300	4.54	58
Massachusetts	1800	..	300	4.23	70
Massachusetts	1800	..	300	3.73	57
Massachusetts	1800	..	300	3.21	55
Massachusetts	1800	..	300	3.01	56
Massachusetts	1800	..	300	2.90	61
Massachusetts	1800	..	300	2.89	68
Massachusetts	1800	1 sq. ft. for each 9 persons	300	2.39	72
Minnesota	1800	"	300	5.15	4
Minnesota	1800	"	300	2.25	80
Minnesota	1800	"	300	2.17	30
Minnesota	1800	"	300	1.63	26
Minnesota	1800	"	300	1.54	101
Minnesota	1800	"	300	.89	29
Minnesota	1800	"	300	.73	28
New York	1800	"	300	.62	25
Montana	1800	..	..	..	..
Minnesota	1800	..	..	4.58	39
New York	1800	..	..	2.73	21
New York	1800	..	..	1.00	20
New York	1800	..	..	.96	38
New York	1800	..	..	.73	18
New York	1800	..	..	.70	40
North Dakota	1800	..	..	3.83	105
New York	1800	..	..	.58	22
Ohio	6 Changes per hr.	..	..	9.2	77
Ohio	6 Changes per hr.	..	..	3.25	76
Ohio	6 Changes per hr.	..	..	3.01	85
Ohio	6 Changes per hr.	..	..	1.95	84
Ohio	6 Changes per hr.	..	..	1.86	35
Ohio	6 Changes per hr.	..	..	1.66	33
Ohio	6 Changes per hr.	..	..	1.25	87
Ohio	6 Changes per hr.	..	..	1.19	88
Ohio	6 Changes per hr.	..	..	.64	90
Pennsylvania	1800	..	..	2.87	3
Pennsylvania	1800	..	..	2.72	51
Pennsylvania	1800	..	..	2.26	79
Pennsylvania	1800	..	..	2.23	110
Pennsylvania	1800	..	..	1.71	100
Pennsylvania	1800	..	..	..	..
South Dakota	1800	..	..	4.80	102
Texas	1800	..	..	.13	103
Texas	1800	..	..	.90	12
Utah	1800	..	..	2.73	69
Vermont	1800	..	..	..	..
Virginia	1800	..	..	.94	15
Wisconsin	1200				

[1] From "Hygienic Problems in Schoolhouse Construction," by Frank Irving Cooper, published in the November, 1919, issue of the *School Board Journal*.

From all the facts at hand we should incline to the opinion that skilled architects and engineers having in mind to comply with the law would so lay out their ducts that comparable results would be obtained. That was the general conception of the investigators; now witness the facts as found by the tabulators. (See Table 2.)

At first sight, one is staggered by the lack of uniformity in these statistics and it looks as if we were far away everywhere from the ideal toward which we should be working. But it should be seen that tables are a record of actual facts and when carefully analyzed they become a history of progress sometimes good, sometimes bad, so that the entire development of each distinct move toward better conditions in our schools may be considered and the contributing forces understood.

DISCUSSION

THE PRESIDENT: It is quite evident that there is a preponderant desire to maintain the mechanical ventilation, although we have not heard from all of the school boards of the cities to which we sent the questionnaires. However it probably is as good an average return as one would expect.

J. I. LYLE: In the next to the last paragraph it is stated that the absentees from a naturally ventilated room increased to an alarming extent. Are there any figures as to the relation of the absenteeism in the naturally ventilated and mechanically ventilated rooms?

J. R. McCOLL: That is given in Mr. Walker's paper read at the June meeting. I would like to correct an impression that Dr. Hill and I conducted the test. It was really conducted by Mr. Frank Walker, Deputy Commissioner of Health of Detroit, and Dr. Hill and I assisted him.

I might state that Mr. Walker and Mr. Palmer, who was formerly on the Board of Health in New York, have been soliciting the Board of Education to allow them to proceed with other tests, not in the same school but in some other school equally as good, of which Detroit has a great many. The Board of Education, due to prejudice against the natural ventilation system, turned the proposition down; but they have agreed to reconsider it and Mr. Walker is now hoping to get permission to conduct other tests.

E. V. HILL: In the letter from Lincoln, Nebraska, the writer stated that the equipment in a certain school there was very similar to the one in the Angell School in Detroit, except that they had no air washer. That is a big exception. I do not believe we should be drawn into any tests or comparisons of mechanical with natural ventilation unless we have a complete mechanical equipment, and I want to go on record as saying that no mechanical equipment is worthy of the name unless it includes an air washer. I think the air washer with the humidity control is just as important as the fan in a ventilating system.

F. I. COOPER: I thoroughly agree with Dr. Hill, that the mechanical plant should be a complete plant.

During the past three years I have made a number of trips to various parts of the country investigating school buildings for the National Educational Association. In September, I was requested to visit school buildings in Minnesota in company with the State Commissioner of School Buildings, and we spent three weeks on that work.

The Commissioner believes in a positive system of ventilation and endeavors to have all new buildings equipped with fans. We visited many buildings so equipped, but in none of them were the fans in operation. The engineers in reply to our questions said, "We don't run the fans until about the first of November because the running costs too much." "When do you stop running your fans?" "Oh, along in April or May." We found that most of the rooms in those school buildings where the fans were not running were unpleasant to enter because of the lack of ventilation.

As engineers, we believe a large school building should have the best mechanical equipment that can be planned, but I believe there should be provision in addition for obtaining ventilation by means of opening the windows.

THE PRESIDENT: It developed in Pittsburgh last year that those who were in charge of the running of those mechanically ventilated plants who succeeeded in running the plants with the least coal had the highest standing. Perhaps that is one of the reasons mechanical ventilation is not as popular in some places as it might be.

E. C. BALDWIN[1]: Mechanical systems of ventilation are all right when they are installed and they will do all that you say they will do, if they are operated. But has anybody ever seen one of these systems in operation except when the designer was around, with his hand on the throttle? Frankly, gentlemen, I have traveled all over this country east of Denver and, except in the City of Pittsburgh, I have never seen a mechanical system in operation. I may have been unfortunate and got around to these places at the wrong time. I came to these various buildings— and there have been hundreds of them—not as a mechanical expert, but as a representative of a school committee and I had an opportunity to see these things. The systems were not operated.

Last winter, I went around to the schools in Boston with the engineer who designed the systems and installed them and with the chairman of the Schoolhouse Commission who paid for them, and this is what I found. We arrived at the Commercial High School about 9:15. The assistant took us into the fan room. Here was an air washer that had been installed. The janitor came in and he pro-

[1] Business agent of the Massachusetts State Board of Education, Boston, Mass.

ceeded to put the air washer in operation. We then went around on the other side of the fan room and then went upstairs. The first thing I ran across was a room where the temperature was over 80 and two windows open. I found that condition in three rooms. That is no fault of the engineer; it is not the fault of the people who install the apparatus; it is the fault of the people that use it.

I might enumerate many cases of that kind—a mechanical system of ventilation, very beautifully designed, very accurately proportioned and excellently installed, is not being used. Why isn't it being used? In this particular school it was the lazy janitor, an indifferent principal and teachers who would not believe that fresh air came in through the inlets. Those are the three things in that school, and we can pretty safely apply that same reason to all systems. Another factor which enters into it, is the desire on the part of the school board to economize in the use of coal. Those four things I have found, in my experience as a user of this apparatus, to be the factors that defeat all that you are discussing here today.

On the other hand I have found some so-called naturally ventilated rooms that were very, very much better. The best schoolhouse that I have ever been in is a school in Canton. The schoolhouse heating apparatus, the arrangement of furniture, everything in the building, was designed by a doctor. He does not attempt to pose as an expert in any way, but he has a schoolhouse there that is a wonder. The next best schoolhouse that I have ever been in was a schoolhouse that had been abandoned because it was unfit for occupancy. The district grew; and this schoolhouse had to be used again—the old Tichenor School in South Boston.

The inspector in charge of that district put some radiators in each room and behind the radiators he put the Eureka ventilator. He used for ventilating purposes, pipes that were formerly used for hot air furnaces; and in the attic he put a chamber, into which he brought these ducts from each room that was heated. When I went into that building, with that primitive system of heating and ventilation—they did not have the mechanical system of today—I found the teachers always at work; I could pass all around the room without attracting the attention of the children. There was better health in that school than in any other in the district and everyone in the school, so far as the heating and ventilation were concerned, was absolutely content and happy. That, from the standard of mechanical ventilation, was the poorest system in the City of Boston; yet everybody was well contented with it.

In that school in Detroit of which mention was made was there any attempt to have the air exhausted by any means other than the open window?

J. R. McColl: There was at the start; the rooms were vented to the attic and then through ventilators in the roof. But inasmuch as the roof ventilators were also used for other schoolrooms, we found

some interference. In a new series of tests which Mr. Walker wishes to make, we intend to use independent ventilators and have independent vents for the rooms.

J. W. H. MYRICK: I would like to state that in Gardner, Massachusetts, in building their new schools about a year and a half ago they were very much dissatisfied with the so-called Massachusetts standard of ventilation, 30 cu. ft. of air per pupil. The absentees from the school and complaints of the teachers and pupils justified this so-called "school committee," appointed to investigate schoolhouse ventilation. The committee was composed of business men and lawyers. They looked over the reports of this Society on file, and stated to the then Massachusetts police that some rooms showed 60 or 70 cu. ft. per pupil and some as low as 15, caused by dropping the transom, or opening a window or a classroom door, the rooms to the leeward side of the building robbing those on the windward side. The so-called Connecticut Wheeler school was called to their attention; the committee accompanied by doctors from Gardner went down and they decided that was the form of school ventilation they wanted because investigation showed that the absentees from that school were less than from any others in the district and the statements made by the teachers and pupils were most satisfactory. However, it was against our rules and our Massachusetts District Police said they would not give them a permit.

I want to say to this SOCIETY OF HEATING AND VENTILATING ENGINEERS, that a great many other committees appointed from the different towns are also much dissatisfied, and this organization should take the stand that mechanical ventilation is better and that it must be operated. These things should be pointed out to these dissatisfied school committees that are spending thousands and thousands of dollars out of school funds.

E. V. HILL: I have been interested in this problem, as you know, a great many years. I have visited, probably, every school in Chicago a great number of times and I have visited a large number of schools in Detroit, in Philadelphia, and Buffalo. In none of these places have I ever visited a school during the session, when the mechanical equipment was not in operation. I am afraid Mr. Baldwin has been going to locations that have not installed mechanical equipment that is up to the standard. We know, of course, that where the equipment is improperly designed there is a large chance that it will not be operated, but where the equipment is properly designed it will be very rarely found that it is not consistently and continuously operated.

I do not know that we should discuss his statement about doctors and business men and so on, designing mechanical equipment. I suppose that, if a man wishes to have a cancer removed he would not go to a plumber, or if a man needed high class mechanical work

on an automobile, he would not go to a preacher. The members of this Society are thoroughly familiar with all these makeshift devices. We have watched the development of mechanical ventilation from just the things these people talk about, that we tried out 20 or 30 years ago, and we have spent probably a great deal more time in testing and watching their results than Mr. Baldwin. It is in an effort to improve this equipment that we have gone to some expensive and sometimes more complicated devices.

E. S. HALLETT: In St. Louis we have to operate our mechanical equipment or we would have no heat. We do not have any radiators in our rooms, that is, in schools that have been built in the last 25 years. We put the heat all into the air and have the mechanical equipment all operated, every day. We have a rule there that if, at any time the school gets colder than 68 deg., that principal has a perfect right to dismiss his school; and you may be sure that the operating end of that plant or that system is not going to have any such comeback as that. So we do have our rooms held within 2 or 3 deg. of 68 or 69, we operate all our air washers every day, all day, and we do operate all of our fans every day all the time it is below 70 deg.

F. I. COOPER: Before this meeting is closed, I would like to call to your remembrance a meeting that occurred in this hall nine years ago. At the request of Mr. Whitten and President Bolton, I had asked Dr. Luther Gulick of the Russell Sage Foundation to speak to us from the physician's standpoint on the matter of heating and ventilating.

One of his charges was, that the heating and ventilating plants would not do what the engineers claimed for them. This charge was taken up by our Society who chose a committee from its members to meet a committee representing the American School Hygiene Association. These committees were to consider the point raised by Dr. Gulick. It was proved and accepted by the medical profession that the engineer could install a heating and ventilating plant in a building which would do what it was intended to do, provided the plant had competent supervision. The real point seems to me to be, shall we demand of the lawmakers legislation that will secure the proper care and operation of the plants we install. It is not right to the taxpayer to demand legislation for the installation of a mechanical heating and ventilating plant and then allow the fan to rust in its place because we have no law to enforce its operation.

F. R. STILL: Mr. Cooper's remarks are directly to the point. We are missing an opportunity to do something that will be highly appreciated by those who have charge of heating and ventilating plants, by our failure to standardize a method of measuring the efficiency of the operation of a plant other than by the coal the operator burns.

The method now universally used is to determine the relative efficiency of the operators by the comparative amounts of coal they burn to operate plants of similar proportions. Some other method should be devised and recommended by this Society. It should take into consideration the results which the purchaser expected he would obtain when he contracted for the plant, and should cover heat, ventilation, humidity, cleanliness and economy.

THE PRESIDENT: A suggestion was made at the Semi-Annual Meeting in Pittsburgh, that the measure of successful operation of a plant should be the lack of absentees. I don't know how that could be worked out.

I want to correct one impression, however; that this Society, favors, to the exclusion of other systems, mechanical ventilation. The Society stands for progress. The Society stands for the best and only the best, irrespective of what it may be. Mechanical and other forms of ventilation will be acceptable in so far as they apply to the particular problem at hand.

No. 544

AN ADVANCE IN AIR CONDITIONING IN SCHOOL BUILDINGS

By E. S. Hallett, St. Louis, Mo.

Member

An increasing stress is yearly being placed upon the housing conditions of our public schools as it is realized that the health and comfort of the child must greatly influence his development. School rooms are occupied to their capacity every day, a condition that accentuates every defect that may exist.

Our cities have become highly artificial institutions and all of nature's resources are greatly affected. The water supply must be filtered and purified, food products must be frozen, sealed or otherwise protected against the universal disease germ. The advancement of science has very greatly lessened all disease and has eliminated *many* of the scourges such as cholera, typhoid, yellow fever and the like.

The remaining plague of the world today are diseases, the germs of which are borne in the air. How slow has science been in fully recognizing this fact. Many years ago Pasteur identified the causative germ of the awful infant mortality and set himself to this task of finding a remedy, which he did in the use of heat in the pasteurization of milk. But the problems involved in making the air that we breathe safe falls to the hands of the ventilating engineer. It has indeed placed a tremendous responsibility upon the profession. His knowledge and discretion must be of the highest order. His path must lead to the door of the physician, the chemist, the bacteriologist, and the keen observing teacher. They must share in the successes and failures that shall intervene before final victory is achieved.

More than two years ago the writer while making a study of the heating and ventilation of the St. Louis schools, was struck with the enormous waste of heat that passed up the vent stacks of all modern buildings. Seven or eight changes of air per hour were being delivered, all of which was discharged from the building after passing once across the school rooms. In the face of all this cost, many

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teachers complained more or less regularly of the heating system. It was apparent that the most nearly perfect system was not satisfactory to either occupant or operator.

It seemed to the writer preposterous that a scientific people as we are, acknowledging no defeat, and fresh from the conquests of science and art, should stand powerless before the task of rendering the air which we breathe a harmless and life-giving element. This struck the writer as a tremendous challenge worthy of the devotion of a life effort if necessary to the accomplishment.

At the outset let us eliminate these subjects which have generally been accepted as having no bearing. The human body requires oxygen to support body combustion, which generates the heat and energy of the human machine. Oxygen is in such abundance that very rarely does it affect ventilation by its reduced quantity. Carbon dioxide is the gas exhaled from the lungs as a result of body combustion, and yet this gas produced in the laboratory in quantities many times greater than is ever found in a school building is not injurious. It is, however, an index to the vitiation of the air and is useful in that respect. The relative humidity affects the comfort of the person, but the means of securing such control of the moisture are well known and on the whole this is the cause of little complaint. It must be recognized that humidity is a function of room temperature which should be based upon the wet-bulb thermometer.

Air conditioning pertains to both the health and the comfort of the individual. The popular mind recognizes only the latter. The health will be affected by the kind of air breathed, while comfort depends largely upon the effect which the air has upon the body surface. It is important to bear this distinction in mind. A bad odor from a harmless chemical starts an alarm of bad air, whereas, a deadly vapor without odor is accepted as good ventilation. The well known test recently made by enclosing several persons in a closed box until the air was oppressive to the subjects resulted in no improvement in the comfort of the men when breathing pure air through tubes from the outside. The experiment being reversed so that fresh subjects breathed impure air through tubes from the inside resulted in no discomfort.

This and other similar experiences indicate that the sensations which we call comfort are the results of impressions on the body surface and do not affect the health to any considerable extent, except as they disturb the mind. The fear of contracting disease from bad odors may actually produce disorder. It is important to separate the studies on producing comfort from those on conserving health.

The scientific method of attack demands that a determination be made of the composition and other qualities of nature's most perfect product. It seemed not impossible to do this, and that it should not be difficult to reproduce that condition whatever it might be. Where have invalids found healing qualities in the air? Some have taken sea voyages; other have gone to the pine-clad mountains of the Carolinas, while others have gone to the desert country of the

southwest. Why not reproduce in the school rooms the air which we so much enjoy in Estes Park? The writer was moved beyond measure at the prospect of such a realization. The benefaction to the race is immeasurable. The results of the experiments of the past two years in the St. Louis schools indicate that this hope has been fully realized.

What is that element or condition of the salt air or mountain valley that is so healing to the invalid and so delighful to all? It is not dryness, it is not lightness due to high altitudes, nor variation in amounts of oxygen or carbon dioxide. It is simply the presence of ozone, or atomic oxygen. Ozone is a natural element in the atmosphere. It is present in increasing quantities on the ascent into the higher altitudes and is probably the cause of the blue color of the sky. It is produced in great quantities by the lightning of thunderstorms and is the source of that feeling of exhilaration so noticeable after such storms.

Ozone is not present in the air of cities because it is quickly consumed by the decaying matter and other oxidizable substances. It must now remain an indisputable fact that human beings require ozone as a normal constituent of the air, and the artificial supply of ozone is nothing but supplying the missing element which has disappeared, due to the results of dense population. Ozone is nothing more than oxygen in an intensely active condition. One great authority likens it to incandescent oxygen. It is made from oxygen by the silent brush electric discharge at a high-voltage of alternating current.

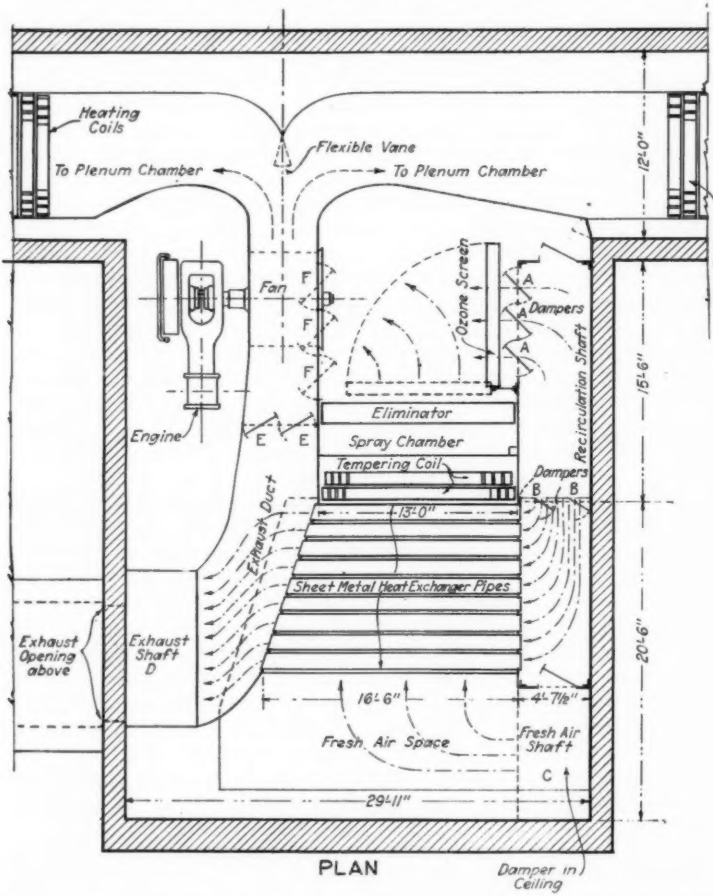
Ozone is a highly active form of oxygen. Its function, whether in revitalizing the air of a school, or in purifying the water of swimming pools, or in the several medical uses, is that of oxidation. Oxidation may be mild and healing, or it may be terrific conflagration. Ozone on account of its highly active chemical affinity must be handled with a full realization of its nature. In this respect it is only like many other of the beneficient resources of nature. On account of the great difficulty of making quantitative analysis of ozone in the low concentrations required in ventilation, there has until now been no guidance for its practical use. It is too low to be rated in percentages. The determinations in nature on the so-called ozone days in those places where it is found, is roughly about one part in a million of air. In such places there is no ozone odor. It just feels fresh.

Ozone has until recently been produced only by the electric spark of static machines, but when produced by the spark or arc, nitrous oxide and perhaps other nitrogen compounds are produced, which are objectionable in ventilation. The improved apparatus now produces ozone without noise or any moving parts, and at a cost so small as to be negligible. The current required for the ventilation of a 24-room school is about 700 watts.

Ozone is the long sought germ destroyer and leaves no injurious residue. We have sought a means of sterilizing the water of the air washer to prevent the spread of disease. We have sought a

means of renovating air ducts to remove age-long smells in old buildings. Ozone accomplishes these results perfectly.

It is noticed that the tendency in recent times is toward the scattering of the heating plant, resulting in added expense and inconvenience, all to avoid the use of horizontal ducts in the system. It has even been proposed to construct the air conduits required for a

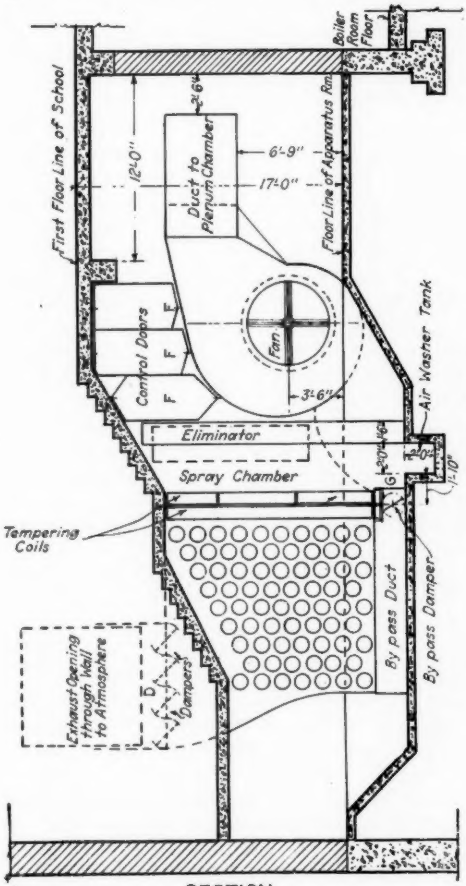


PLAN

heating system so that they may be thoroughly washed out. The use of ozone is equivalent to burning them out—rendering them perfectly odorless and sanitary. The Government Public Health Service has issued a bulletin in which it is shown that ozone is the best and most practicable means of sterilizing drinking water. It is a complete germicide and leaves no taste or other objectionable result. Some European cities purify as much as 24,000,000 gal.

of water per day in this manner. These, with many other authentic practical installations, establish the fact that ozone is the long-sought harmless sterilizer.

Upon making a search of the literature on the practical working of ozone in school rooms, it was found to be wanting in this country. Quite extensive use has been made, in ventilation other than schools,



SECTION

FIG. 1. NEW DESIGN OF HEATING SYSTEM FOR SCHOOL BUILDING OF THE ST. LOUIS BOARD OF EDUCATION, SHOWING METHODS OF INCORPORATING OZONE APPARATUS.

in Germany, France and in the subways of London, and all with the highest satisfaction. It was necessary then for the writer to carry out tests that would have value and under such medical supervision as would inspire confidence.

Search was made for ozone apparatus which would produce pure ozone and under such control as would determine proper concentration.

It happened just at this juncture that our Doctor Stewart, the head of the hygiene department of the Board of Education, came to the building department with a complaint from one of our downtown schools that the air was so bad in some rooms that certain teachers threatened to resign on the advice of their physicians.

This school in question was equipped with a plenum heating system with air washer in good order and the full quota of 1500 cu. ft. of air per minute to each room. An examination was made of all conditions and the ventilating apparatus was found to be perfect in operation, but the children in this district were from families of foreigners who never bathed. It is a fact that many were sewed up for the winter. They ate garlic and such foods, and it was this highly odoriferous condition that was causing the complaint. There was in addition a prejudice against the heating system and the department in general because they were not permitted to open windows in cold weather. The writer proposed to the hygiene department that the ozone experiment be started in this school.

The apparatus was set up in the air passage between the air washer and fan, and regulated to produce just sufficient ozone to be barely detected by the odor on entering the building, but not enough to make one conscious of an odor. The result was the immediate disappearance of all the stuffy condition and bad smells complained of. The remarkable thing was that every teacher and the principal pronounced the ventilation perfect. They stated that the conduct of the children as to lessons and behavior was noticeably better. No drowsy afternoons followed. Teachers stated they were as fresh at the close of the day as in the morning. Colds and coughs nearly disappeared. No contagious disease developed during the six weeks trial, although the influenza was epidemic at this time. On several occasions a check was made on attendance and not an absentee was reported on account of sickness.

The building was not constructed to permit perfect recirculation of the air, but the fresh air intake was closed down to 2 in. and the door to the basement was opened and the air drawn through (the economy even thus gained was about 25 per cent in coal). During this period of influenza epidemic of February and March, the attendance in this school was more than 3 per cent higher than the general average for this school.

The experiment was then transferred to a colored school having a plenum system with the Zellweger air-washing fan and with the complete recirculation of the air. The ozone machine was set up just back of the fan, the ozone acting upon the water of the air washer as well. In this test the pupils and teachers were weighed weekly and a close inspection made by the staff physician of the hygiene department. The data from the weighing were interesting and instructive. About 75 per cent of the children gained in weight on an average of about 1 lb. each. About 20 per cent made no change and about 5 per cent lost weight. Several very fat girls weighing about 175 lb. each lost weight from 5 to 8 lb. No indication of any illness or discomfort was noted. The principal

who was an old man, perhaps 70 years of age, weighed 218 lb. and was quite inactive, after about a week complained of dizziness and of feeling badly although on duty regularly. He lost 15 lb. in weight. The physician made daily examinations and was at a loss to explain his condition. He was not sure whether it was due to ozone or merely a coincidence. But after a study of the weights of the children it was decided that the ozone had caused a rapid oxidation of the superfluous tissue and that it had been poured into the lymphatic system faster than the kidneys could remove it and the result was the illness stated. It is interesting to note that this principal has been in better health since that time and is anxious to have the ozone installed permanently. It is simpler than exercising for reducing weight.

No contagious disease occurred in this school. Both parents of one family died of influenza during this period and neither of two children in school contracted the disease. Colds were noticeably less. This colored school was perfectly free from odors. The coal consumption was measured and in comparison with days of equal outside temperature, the coal used was almost exactly one half. Agar plates were exposed in a room filled with pupils and the average count of bacteria was 225 which was extremely low, indicating that the ozone had destroyed the active germs of the air.

Further test was made of another school having complete recirculation without the air washer. In this school no teacher or pupil was aware of the experiment and after ten days the principal sent a note to the teachers to report whether worse, or better, or no change. Three had observed no change; all the others reported that they had noticed improvement; some were enthusiastic. One had first observed a marked improvement in the work of the pupils and was unable to account for it. One said it was delightful. No complaint of poor ventilation had come to his office during this period. The principal volunteered the statement that he was sure it was a great improvement. The economy in coal was a little less than 50 per cent.

To sum up the results of a year's tests with ozone in the schools, the following facts are indicated. Ozone does destroy all odors resulting from the respiration, bodies and clothing of the children. It produces a mild exhilaration resembling that of a sea breeze or the air on a morning after a thunderstorm. It removes smells from the building due to lodgment of dust in ducts and the like. It destroys toilet room odors. When used in proper concentration for ventilation it has no odor itself. It reduces weight in persons corpulent from inactivity. It appears from limited data to be a preventive of influenza. It undoubtedly is of great value in the treatment of influenza and pneumonia as demonstrated in the influenza hospital in St. Louis last year. To this should be added the evidence adduced by the medical authorities of France that ozone increases greatly the oxyhaemoglobin of the blood thereby increasing the oxygen carrying capacity of it. This in turn cures anemic persons. The introduction of ozone in ventilation would probably

remove the necessity for open air schools now common in most cities.

The results of these practical tests in schools under strict medical supervision mark an epoch in ventilation and call for a complete recasting of present ideas on the subject. There can be no more replowing of the old field. Some of the old heretical doctrines must be gotten rid of. The first one is—that heating and ventilation are separate and distinct problems. The heat must be incorporated in the air to be utilized by the individual and it should be so incorporated in the most efficient and thorough manner. Can any operation be more perfect than a blast fan blowing air through the interstices of a bank of vento coils? Can any operation be more defective than the action of direct radiation around the walls with the air entering at the ceiling at one end of the room? The only purpose of making the heating and ventilating problems separate is that the ventilation may be conveniently dispensed with. The heat must all be carried in the air. This is now made imperative by the necessity of incorporating the ozone in the air and the air movement is still essential.

Having carried out these experiments to the satisfaction and enthusiastic approval of all concerned and having discovered what seemed to have heretofore prevented the introduction of ozone in ventilation, it is deemed proper here to give some concrete details governing the installations in school buildings. In the St. Louis experiments it was early determined that in ventilation with ozone the maximum concentration should be too low to give an ozone odor.

Tests were made to determine the effect on teachers and pupils when used up to that maximum—no illness or discomfort was detected in normal persons. On the contrary a mild exhilaration was experienced in every way similar to that of the refreshing sensation after a thunderstorm. As previously noted, the very corpulent persons lost weight and in the case of an old man leading a very inactive life, ozone caused dizziness and headache for several days. The net results of this experience were of great benefit to all the persons. It reduced the weight to the extent of the inactive tissues. A few persons at first felt a roughness of the throat, a slight over stimulus of the mucous membrane, which disappeared within two days. It has therefore been demonstrated that ozone used in a concentration up to the point of producing an ozone odor is safe for ventilation. This may be called one of the calibrating points in the scale. However, persons not used to ozone air must be used for detecting the odor as the sense of smell for ozone quickly declines when one is exposed to it.

Having ascertained that chemical means of determining the quantity of ozone for ventilating were impractical, the writer proceeded to develop a standard from the manufacturing standpoint, which may be used in determining in advance the proper concentration for any given volume of air movement or for a given number of occupants of a room.

This standard was developed after ascertaining that with a given voltage and with a given thickness of dielectric, the amount of ozone generated was proportional to the number of brush discharge points of the generator.

The most satisfactory, apparatus uses 4000 volts alternating current from a static transformer, all inclosed with the ozone generator unit, which uses a micanite plate dielectric, 0.040 in. thick and aluminum points spaced approximately ½ in. apart. It was observed that 600 brush points made just enough ozone for 1000 cu. ft. of air from the blast fan.

This test was with rooms filled with 45 to 50 children much below the average in cleanliness. For rooms occupied by fewer persons, the brush points or voltage should be reduced. If conditions are to remain constant, some points should be disconnected but with varying conditions a controller should be installed to regulate the voltage by taking taps out of the primary of the transformers.

Where the air is recirculated in whole or in part, the ozone must be cut down to the point where no ozone odor is noticeable. In fact the revitalizing of the air of the average school room when recirculating 90 per cent of the air will be effectively done with half the maximum stated above. The writer believes that the delay in the use of ozone in ventilation has been due to trials made with too high concentration and to the absence of any information on a means of control.

It is also true that until recently ozone was produced by static discharges through the air, the open arc or spark producing nitrogen compounds which were objectionable for ventilation. Ozone should be used with the blast fan to get uniform distribution, and the ozone machine should not be started until the fan starts.

Where it is desired to use ozone to take the place of ventilation in rooms with direct radiation, a small apparatus with a fan self contained should be used to distribute the ozone. It is fortunate that ozone is heavier than air and tends to get to the lower stratum of air which is the impure stratum. Ozone does not destroy dry bacteria but destroys most species of germs when moist and if sufficient humidity is maintained in an unventilated room the moisture of the mucous membrane will be sufficient to enable ozone to destroy most bacteria. The efficacy of ozone in destroying bacteria is illustrated in the treatment of the water in swimming pools by which one part of ozone to a million parts of water renders it sterile. This is upon the authority of the United States Public Health Service. In this case ozone destroys the bacteria and oxidizes other objectionable solid and liquid matter of the pool to inert substances. This is incorporated by providing a circulating pipe 4 or 5 in. in diameter taking water from the bottom at one end and returning to the top at the other, the ozone being pumped into this pipe at the base and caused to act as an air lift to force the circulation. The ozone is incorporated in this oblique upward travel.

The results obtained in these experiments call for a recasting of all our ideas on heating and ventilation. In the attempt to improve

the systems, much superfluous junk has crept into even standard specifications. With a reliable means of revitalizing the air the sizes of boiler, fan and air washer are greatly reduced. As the air carries within itself the revitalizing element, a small variation in air flow will not affect the children. The expensive hot room and tempered-air chamber together with the individual duct and mixing dampers may be dispensed with. The writer therefore in view of all these facts set out to design a heating system that should be accepted by everybody as perfect. Recognizing that perfection is not a human trait he offers this as perfect in a relative sense.

Fig. 1. shows a plan and sectional view of apparatus room of the last building designed by the St. Louis Board of Education. It will be noted that the plant is concentrated into compact quarters. The vented air goes to the attic without galvanized iron ducts, only the heated air being carried in iron ducts. The vented air passes up the concrete shaft about the heat ducts. To avoid heat losses in the attic, an insulated trunk duct picks up the air from the shafts at the end of wardrobes. This vented air is delivered through the ceiling into the apparatus room as shown. This air may pass through control dampers and the ozone apparatus directly into the fan with 10 per cent or any other amount of new washed and humidified air, the proportion being at will or dependent upon the house leakage.

The foregoing sketches the apparatus for winter service. We require close regulation and a drop of 3 or 4 deg. in temperature is the occasion for dismissal of the room. Custom has led us to tolerate but 2 or 3 deg. of cold below 70 deg., but we tolerate more than 20 deg. of heat. The loss of money and efficiency on this account is enormous. During September of this year the schools of St. Louis closed part or all of five or six days. Counting the cost of the schools for these days it was easily a loss of $100,000.00 to say nothing of low efficiency due to heat.

Since all things are reckoned anew it occurred to the writer that the temperature control should operate throughout the whole year, and since the air can be recirculated the humidity can be kept down and the comfortable temperature easily maintained.

The air washer is of no value as a cooling device for schools, because the humidity thus raised produces more discomfort than the heat. So in designing the new building exchanger pipes are installed to take all the returned air. The outside of these pipes is cooled by either the new air from the washer or by a direct spray of water from the washer system. These pipes are an integral part of the system and take the place of the tempering vento coils for the tempered air room, so that the plant is really an all the year around conditioning apparatus, that shall make it a delight and a refuge from all extremes of the climate.

In closing permit me to say that every statement made here which may seem revolutionary is nevertheless based upon authentic engineering data and experience and admits of complete verification. It is the hope of the author that the bold claims herein set forth may be verified and utilized in the schools of all our cities.

DISCUSSION

The Author: This paper was written to give an account of the experimental work that we have been carrying on in the schools of St. Louis in the past two years. I came into the employ of the Board of Education of St. Louis a few years ago and when I began to study the system I found an enormous waste of heat due to the fact that the air was heated, washed, made as fine as could be, passed across the rooms once and out at the stack. We made tests of that air as it left the rooms and found out it was far better than the incoming air. Now it seemed to me that it was preposterous that we should waste that heat especially in view of the increasing cost of coal.

We are all familiar with the facts in regard to the other elements, the presence of oxygen and the CO_2 and the condition of the humidity. Those are standard facts that we are all agreed upon. It occurred to me that our schools, where the young folks are gathered together all day long, ought to have the best air that can be provided. People go to the sea coast and spend the summer and go back refreshed, with no question at all about the invigorating effect of the fresh air from the ocean, salt air, so called. Others go out to the Rocky Mountains and spend the summer in delightful rest, and the refreshing air there is undoubtedly of value in recuperating.

Now it occurred to me to ask the question, "Why should not the children in our cities have just that kind of air?" And so I proceeded to find out what it was in the sea air and in the Rocky Mountain air, that gives us that invigorating, exhilarating sensation. The survey eliminated everything except ozone, which was common in all those cases. I then first attacked the ozone problem, as it has been attacked many times. Ozone is not new, of course. I found quite a good deal of literature. I found some of the most eminent men we have who have done work upon it. I have Steinmetz's statement that occurred in the *Electrical World* two or three years ago, in which he advised somebody to undertake practical experiments. He said it needed some more experimental work to tell what could be done about it. In that same article he stated that ozone was oxygen, acting much like incandescent oxygen.

Well, then, with a gift like that in our possession, without any injurious qualities about it except its intense activity; and with the presence of oxygen in our makeup, the fact that our blood carries oxygen and that its most important function is to distribute the oxygen to the tissues and organs; with such an agent, free from any injurious qualities, it seemed that we certainly could revolutionize our heating systems, and I proceeded to work at it. This paper tells what I did in that connection.

We have in our city a Hygiene Department, headed by Dr. James Stewart, who is a practicing physician of many years standing, of high repute in the city. He had under him a corps of assistants, all physicians, and an additional corps of nurses who were inspecting

the schools. We took the stand that whatever was done must be done with the weight of authority and the work inspected by physicians whose standing is not questioned. And so we proceeded to install ozone apparatus.

I proceeded first with the worst school that we had. We had one of these downtown schools, inhabited by people who have not learned the American ways of cleanliness. These children came unwashed and with the kind of food that gave out diversified odors; and we had some teachers at this particular time who had been ordered by the physician to resign, because their health demanded that they get out of that kind of place. The apparatus was set up in the fan room. We have a blast fan, of course, supplying the air. St. Louis believes in using an abundance of air. It is probably true that we have the biggest problem of air moving in the country —7,000,000 or 8,000,000 cu. ft. a minute. Now that is a good deal of air to move for one system of schools, but we are insisting on having our fans operated. They operate all day, every day. We put this ozone apparatus in the air conduit and immediately, I found what seemed to me the reason for the failure of ozone in the past, which was that it has been used at such a concentration as to become a nuisance in itself. At once the concentration was limited to an amount so low as not to produce a smell of ozone in the house.

I have told in this paper just what results came from it. I found that the teachers who had been continually complaining and could not be satisfied, were enthusiastic about it; that the stuffy conditions that had been complained of and the odors that had been present before were disappearing; disinterested persons, including Dr. Stewart and his staff of doctors assigned to the districts visited the schools, and said that the schools were delightful. Some other remarkable things occurred, in fact, a good many of them. I prepared a little questionnaire and had the blanks passed around, without any instructions or coaching or advice as to what they should say. We wanted the truth. I told the principals that I did not want anything except what they felt like writing spontaneously. I will read some of the questions and answers:

"What general effect has ozone had on the school?" Ans. "My disposition is much better, not feeling cranky. The children, of course, are better, easily managed and are doing better work."

"Has it affected the mental activity of the pupils?" Ans. "There is an improvement as far as I can see in the short time the machine has been in use."

"Has it affected their behavior?" Ans. "Much and decided".

"What have you observed as to the health of the pupils?" Ans. "Free from colds, and when a cold does get a start it does not last long."

"Has it affected the regularity of attendance?" Ans. "The most regular attendance I have ever had during winter weather."

"What is your personal experience as to fatigue?" Ans. "I feel like a different person; that is, not much more tired at 3.30 than at 8:30."

"Has it in your opinion prevented you from loss of time on account of sickness?" Ans. "It probably has. (I put that question in because the principal said that was the first year in which none of the teachers had lost any time. The principal is more enthusiastic about that, because she had been constantly having to have substitute teachers in the schools, which had not occurred while this was in operation.)

"Has ozone had any objectionable features?" Ans. "None as far as I can judge. I wish we had had the machine or plant for years instead of for months."

One uniformly good result from this, is that it prevents fatigue. When the fuse had been out for two or three days they said that they had not realized before what it meant to get back to the old conditions of weariness at the close of the day of school; that it was very pronounced; that it had prevented fatigue.

We carried on this first experiment last year. Then we moved the apparatus to another school, a colored school, in which we had a similar heating apparatus. We had an air washer in the first school, in which the ozone did not go through the water of the air washer but in the next one the water was treated likewise. We recirculated the air entirely and the intake was closed up and no new air was taken in except barely enough to make up the pressure— barely 10 per cent. We weighed the children, the principal and teachers every week and here is the result:

We found about 75 per cent of those children gained in weight. Another 20 per cent of them made no change and 5 per cent lost weight. The losses were much more pronounced than any of the gains, and when we examined the kind of people that lost weight we found they were corpulent. We had some girls there 12 and 14 and 15 years old that weighed 175 or 180 lb., and they had lost 6 to 8 or 9 lb. We had a principal, an old man, a very quiet man, and a man who seemed to have no exercise and no activity except when he walked to the school and back. He weighed 218 lb. He lost 15 lb. in two weeks.

An interesting study developed from a reference in Mr. West's paper that he read here last year, in which he stated that the electro-static pressure in schools were probably the cause of more or less irritation. We found, in the production of ozone, that we used alternating current which alternately brought the plus and minus charges through the apparatus and I do not doubt at all that the correcting of this electro-static pressure in the room had something to do with this pleasing sensation that every one experienced in these experiments. It is certain that the ozone apparatus does destroy this electro-static condition. We have had evidence, of course, of such conditions. We have had deposits of dust on one wall which could not be accounted for in any other manner.

When it had been settled in my mind that we could purify the air with a concentration of ozone that was entirely unobjectionable, which after trial and after careful medical examination, had no objectionable features, it occurred to me that a fresh study of the

whole heating and ventilating scheme should be made. We immediately made up new plans and considered everything from the beginning; why we should have recirculation. We found that the recirculated air with ozone was better. Why? Because it gave better satisfaction in rooms than air without ozone that was constantly changed, even when it was changed every five or ten minutes. That thoroughly established in my mind that we should redesign our plants so that we could have recirculation.

One further thing came to me in developing that apparatus. I realized that there was a chance of having an all year round conditioned building. I realized that the air could be cooled by bringing this air down through here and around through the tubes in the exchanger and back into the fan again, while putting the spray of water on these galvanized tubes, not permitting the humidified air to mingle with the air of the house. The reason that air washers, as you know, cannot be used for cooling in hot weather is that it raises the humidity to a point that is worse than the heat. But this now separates the humidified air and enables us to keep the air dry without expense. The idea is to have an apparatus that shall not be expensive. It is really an advantage to have it cheap, to have it so that people will put it in and use it. I wanted also to determine, if possible, what demand there was for an all the year round building, provided it did not cost too much. It is an innovation that would probably have to grow.

S. J. BROWN: When you removed that apparatus from the original school to the colored school, what condition did you find in the original school? Did you revert to the old condition when you removed that apparatus?

THE AUTHOR: Yes, we had but one apparatus. When cold weather set in again this fall I re-installed the ozone in this school, for we had war on hand. They could not do without it.

E. V. HILL: Did you ozonate the water?

THE AUTHOR: We ozonate the water separately in some cases. We tried that. My own opinion is, that with the air washer when recirculating air, it is not necessary to specially ozonize the water, for the air itself carrying ozone will sterilize the water.

H. G. ISSERTELL: Did that affect the ducts?

THE AUTHOR: There was no indication that it affected the ducts. The galvanized iron, of course, would be attacked in time, for there is no question that zinc has an affinity for oxygen. It will attack most metal. It attacks brass more rapidly than any others.

W. G. R. BRAEMER: Have you operated this in the summer?

THE AUTHOR: Yes, I operated it in one of our schools when it was above 70 deg. outside. We kept the house closed, moving air through the building with the ozone, and not a single one of those teachers suggested having the windows raised. That was very remarkable.

W. G. R. BRAEMER: Did you operate the air washer in the summertime also?

The Author: No, not the air washer with the recirculated air, we can't do that long on account of rising humidity.

W. G. R. Braemer: My reason for asking that question is that you said that you used the washer water or the air from the air washer to pass through the unit through pipes.

The Author: Yes, those pipes, would be cooled with the reversed air, as we have this designed. But the air can be reversed and pulled back across those tubes. One can use that method or put a spray immediately upon them.

W. G. R. Braemer: I cannot understand how you can get the air from the washer through the tubes unless you operate the washer.

The Author: No air would be taken into the house through the washer in the summertime, but the air would be discharged at this point. It would be taken from outdoors and returned outdoors.

W. G. R. Braemer: That is the point, I suppose. It is a well known fact that if water is recirculated in an air washer, the temperature of that water gets to the outside wet-bulb temperature. Now in St. Louis you frequently have a high wet-bulb temperature in the summer, from 75 to 81 deg. I have had considerable experience in cooling work and I don't see how any appreciable cooling can be done with a cooling surface from 75 to 81 deg. I think you will need an enormous cooling surface to do it. In fact, I don't believe you can get any cooling results worth while on that basis.

The Author: The air coming back seven or eight times per hour through these same tubes is equivalent to lengthening them. They are only 12 or 11 ft. long, but the air repeatedly coming back each time loses a portion of its heat. The spray of the water can be used and wasted in some localities if it is found that sufficient cooling effect does not come from the water vaporized.

W. G. R. Braemer: There will be a difference of temperature, perhaps, between the cooling surface and the incoming air, of a few degrees, but I can't see what cooling can be accomplished if air is coming into the rooms at about 80 deg.

The Author: 90 deg. We don't care for a temperature lower than 89 deg.

W. G. R. Braemer: Furthermore, if the air is recirculated as you propose, the humidity is bound to increase.

The Author: What we are doing does not increase the humidity in the house at all. We do not permit this air from the air washer water to go into the house system. This would be simply using the cooling effect of the evaporation on the air.

W. G. R. Braemer: I understand that, but if the air were recirculated continuously there is bound to be evaporation from the occupants of the room and consequently the humidity is bound to increase.

S. J. Brown: May I ask whether or not this is a patented process and is it available for other schools than those in St. Louis?

L. L. Lewis: Had you any data as to the relative temperatures inside the building and outside the building, when you were using the air washer as a cooling proposition?

J. R. McColl: I had occasion a few years ago to conduct some tests along this line in the general offices of the Detroit Edison Company. I took care of the ventilation tests and the Detroit Testing Laboratory, the chemical tests. There was quite a test of the efficiency of the use of ozone. We carried on the tests for some time, possibly a year or two. In the meantime, however, the enthusiasm for ozone was gradually falling off, and the net result seemed to be that the impression was a psychological one and the physiological benefit was not true. They finally abandoned the use of ozone in their ventilating systems.

I would like to ask the author if he made any tests as to the proportion of ozone he used in the ventilation.

W. G. R. Braemer: I would like to ask Mr. Hallet if he has ever attempted to figure out the cooling surface required to produce any appreciable cooling results.

The Author: Is this available for everybody? It certainly is. I am trying to do research work for the Board of Education of St. Louis, and that is my only interest. The parties developing this apparatus are claiming protection on it.

We all have the data that are published in regard to the cooling effect of air washers. That is abundant when no additional moisture is incorporated in the air of the building. That of course would hold good here. We have data as to the amount of heat transferred through galvanized iron ducts, which is about 2 B.t.u. per sq. ft. per deg. of difference. That is all that we expected, as the cooling effect was a secondary consideration. This was not made as a cooling apparatus in the first place. While we were considering it and had this information on hand, I wanted to ask how much demand there is for such an apparatus. I made this suggestion a while ago as a possible means of handling it without expense at least to that extent. I know as well as you, that in very high humidity, in very hot weather, we would have very great difficulty in using air washer water to cool with. We would not get anything from the evaporation. But there is always cold city water in the mains, which can be used and wasted on these pipes to bring down the temperature, which could easily be kept 5, 10 or 15 deg. lower than the outside air.

The next gentleman asks the proportion of ozone. There were no tests made to learn the percentage of ozone. I am familiar with the work of research men who have spent 15 years in this study and the determination of the amount of ozone in the air for ventilation is found to be an extremely small percentage. The percentage in natural air, it is stated upon fair authority is one in 1,000,000 to one in 3,000,000 of air. The point that I made in the paper that I have given you today is that until the air commences to give the odor of ozone, no possible harm can come to the people breathing it and no objection can exist whatever to the use of ozone if it is kept at that point. Half of that amount will give a result which will burn the tobacco smoke and take the tobacco smell and things of that kind out of the air.

No. 545

PROGRESS IN THE DEHYDRATION INDUSTRY

BY C. E. MANGELS[1], WASHINGTON, D. C.

Non-Member

THE preservation of fruits and vegetables by dehydration has been given much prominence during the past three years. Dried fruits have been staple articles of food for a number of years, but the dehydration of vegetables presented many problems not met in the drying of fruits. Fresh vegetables wilt or spoil much more quickly as a rule than fruits. The slow processes used for fruits have not therefore been applicable to vegetables.

Dehydration of fruits and vegetables has been, and still is, a very fertile field for investigation. Dehydration became still more important to us when the United States entered the war, and the necessity for vegetable foods in a concentrated form became apparent. The United States Department of Agriculture, particularly the Bureau of Chemistry, has conducted extensive investigations on the preservation of fruits and vegetables by dehydration. These investigations have had a very wide range, and the problem has been attacked from many different angles.

When the United States entered the war in 1917, a vegetable dehydration industry already existed in Canada. The plants in Canada dehydrated vegetables for the allied armies, the principal products being dried sliced potatoes and the Julienne soup mixture. A few plants engaged in the dehydration of vegetables existed in this country before the war, and the declaration of war by the United States gave impetus to the enlargement of existing plants, and the formation of new organizations. Unfortunately, there was also created a very fertile field for stock-selling schemes and exploitation of worthless patents.

When the armistice was signed in November, 1918, a number of plants were engaged in the dehydration of vegetables. Practically all of these plants were engaged solely in the filling of Army contracts, and had not even attempted to develop any other outlet for their products. Consequently, when all outstanding contracts were cancelled by the Army in February, 1919, the whole industry was

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placed in a very precarious condition. The outlook for dehydration was unquestionably discouraging but many of the manufacturers immediately made plans for the development of other outlets for their products and planned primarily to develop a domestic market. The success of their efforts has been encouraging. Not only have many of the existing plants continued to operate, but new organizations have been formed and new plants erected during the past year. Dehydration has not been merely a war visitor—it has come to stay.

The products produced for Army use were not unwholesome, but their quality was not such as would tend to create a strong domestic demand. The first step, therefore, in creating a domestic market for dehydrated products was the improvement of the products. While perfection has by no means been reached, the improvement in quality during the past year has been remarkable.

How has this improvement in quality been accomplished? It has not been accomplished by any extensive changes in the drying equipment of these plants. Excellent drying equipment, we find, does not necessarily produce excellent dehydrated products. The products produced this season have, as a rule, been more palatable, have had a more appetizing appearance, and have better keeping qualities. While many manufacturers have in the past been able to produce palatable dehydrated vegetables of good appearance, the products generally would not hold up in storage at ordinary temperatures even in sealed tins.

Two types of spoilage have been common in dehydrated vegetables. The hardest type to control is the infestation by moths and other insects. The other type of spoilage is due to chemical changes which are not associated with bacteria and molds, but are probably due to the action of oxidases or enzymes. The Division of Dehydration has conducted investigations as to the action of molds and bacteria on dehydrated products. All of the data secured to date indicate that dehydrated products will not be subject to spoilage through the action of molds and bacteria when stored under reasonable conditions. Molds appear to require a moisture content of at least 20 per cent for their development, in case of fruits and 12 to 15 per cent in case of vegetables. The average moisture content of dehydrated vegetables is well under 15 per cent, generally 10-12 per cent. Bacteria in dehydrated vegetables decrease in number on storage.

This deterioration in dehydrated vegetables due to chemical changes is manifested differently in different vegetables. In the case of cabbage and onions the dried product becomes brown in color, and loses its characteristic flavor. In the case of carrots the red color disappears, at times associated with the darkening of color and loss of flavor. Our observations indicate that in most cases these changes are due to the action of enzymes or oxidases. Neither the type of dryer nor the system of drying appears to be a factor.

Several factors tend to control these changes, which further lead us to believe they are due to the action of enzymes or oxidases.

Investigations have shown that the moisture content of the product is a factor which controls the rate at which these destructive changes take place—the lower the moisture content the slower the rate of deterioration. At ordinary room temperatures vegetable products with a moisture content above 10 per cent deteriorate quite rapidly—in four to six weeks—while the same products with moisture contents of 3-5 per cent show no changes until after 4-6 months of storage. Improvement of the keeping qualities by drying to a very low moisture content is not commercially practicable, however, for two reasons. First, the removal of this extra moisture means a longer drying period, a higher cost of drying, and especially a greater danger of scorching; second, after drying the product to this low moisture content, it is necessary to pack it in moisture-proof containers in order to avoid absorption of moisture from the atmosphere. The average commercial moisture content of dehydrated vegetables is approximately 10 per cent.

It is also true that samples of dehydrated vegetables with a moisture content of approximately 10 per cent showed no deterioration when stored in a refrigerator at a temperature varying from 32 to 40 deg. fahr., while the same samples would show a very marked deterioration when stored a like period of time at a room temperature of 70 to 80 deg. fahr. The cost of refrigeration makes this method impracticable.

This deterioration, as previously stated, is not associated with bacteria or molds, but may be attributed to the action of oxidases or enzymes. The destruction of these enzymes should, therefore, prevent this deterioration. Enzymes are as a class easily destroyed by heat and, therefore, by blanching or slightly pre-cooking the vegetable before dehydration, the enzymes present are destroyed. This is accomplished by dipping the vegetables in boiling water or steaming a short length of time before drying. This treatment has proven very effective in preventing this type of deterioration, and is now in use by practically all of the dehydration plants. Blanching or processing with steam or hot water is an art rather than a science. As manufacturers master this art, the products will improve in quality. Several factors will always influence the method and the time used, for instance, the product, the manner in which it is cut or sliced and in some cases the variety and state of maturity.

Insects, particularly moths, were a serious menace to the dehydration industry last year. The moth commonly found in infested products is known as the "Indian meal moth." In cooperation with the Bureau of Entomology, United States Department of Agriculture, we have outlined apparently successful methods of control. The usual practice in dehydration plants had been to store the dehydrated products in open bins previous to packing. This practice offered

an excellent opportunity for the adult moth to deposit eggs on the dehydrated products, which eggs developed into larvae after packing. By packing immediately after dehydrating in moth free rooms, or storing in moth tight bins, the deposit of eggs is practically eliminated. Infestation may occur later, however; when dehydrated products are stored in ordinary cartons the larvae of the moths may gain access to the material through the crevices of the package. Packing in a moth proof carton would, therefore, be highly desirable, although the principal point of infestation is before packing.

The keeping qualities of dehydrated vegetables have been greatly improved by controlling these two types of spoilage. Improved operating conditions and attention to details have largely eliminated the scorched, over-dried unpalatable product of the past. One practice—the use of sulphur dioxide fumes—has been practically eliminated in vegetable drying. The reason is simple. The sulphurous acid obscured and destroyed the delicate flavor of the vegetables.

During the war, dehydration plants were principally concerned with the dehydration of vegetables. Since the war, however, when located in a fruit producing region, these plants have given much attention to the dehydration of fruits. This is particularly true on the Pacific Coast. Dehydration plants have been able to produce products decidedly superior in quality to the ordinary sun-dried or evaporated fruit. These "dehydrated" fruits (as the producers choose to call them) have a flavor very closely approximating that of the fresh fruit, and when placed in water more nearly resume the texture of fresh fruit. The products of dehydration plants are sulphured much less and contain on an average 5 per cent less water than the ordinary dried or evaporated fruit.

A rather higher moisture content has always been permissible in fruits due to the high acid and sugar contents, which tend to act as preservatives. In the ordinary dried or evaporated fruits the moisture content is often high enough to be favorable to the development of molds. The moisture content of the "dehydrated" fruit is generally under 20 per cent.

Sulphuring of fruits has long been practiced on the Pacific Coast. Sulphur dioxide fumes are used to bleach the fruit, before drying, and the retained sulphurous acid acts as a preservative after drying. Sulphuring no doubt facilitates handling of the fruit, but heavy sulphuring is very objectionable. The sulphurous acid obscures and destroys the delicate fruit flavor, and in heavily sulphured products we have left only a tart or sweet taste.

The dehydration plants use sulphur dioxide as a bleaching agent only and not a preservative. The products are sulphured very lightly and the sulphurous acid is removed from the products in the process of drying. The fruit is generally given a short steaming before drying and this steaming, together with the lower moisture content, assures a product of good keeping qualities.

There has been little or no change during the past year in the drying equipment of existing plants. Two attempts were made to use a moving belt dryer for dehydration of fruits and vegetables. One attempt was wholly unsuccessful and the other only partially successful. A plant must be able to handle a variety of products—both fruits and vegetables—in order to prolong the operating season and thus cut down the overhead expense. A dryer, using trays, is essential for some products, notably the softer fruits, and therefore any type of dryer in which trays are eliminated will have a very limited use. In one essential, all of the dehydration equipment is similar—air is used as a medium for conveying heat to the product and carrying away the evaporated moisture. In the simplest type, atmospheric air is heated to the desired temperature, passed over the product and discharged. In other types, the relative humidity of the air is raised (in some cases as high as 60 per cent) by recirculating the air. The majority of dryers may be classed as tunnel dryers and many other drying units are essentially modifications of the tunnel type. The kiln-type is of course an exception.

Vacuum dryers have been used in various industries for some years, and are at present used for the drying of milk. Vacuum has long been a laboratory aid to the chemist in drying food materials. While fruits and vegetables of good quality can be produced in a vacuum dryer, their quality is not superior to those dried in a current of air. Further, the most expensive type of dryer using air as a medium of evaporation is much less expensive per unit than vacuum dryers.

While there has been very little change in the type of equipment during this past year, it does not mean we have reached perfection in equipment. There is yet much room for improvement in drying equipment, but if anyone expects to see existing plants dismantle and replace their equipment he is certain to be disappointed. The equipment will be improved by minor changes in the existing equipment. We wish especially to caution inquirers that dehydration of fruits and vegetables presents problems quite different from the drying of textiles, soaps, etc. Unfortunately, many designers of plants ignore the fact that they are dealing with a product which has a cell structure and that the water must be removed from these cells without injury to the cells.

An industry very closely related to dehydration has developed in the past two years—the potato flour industry. Mills are now operating in at least five states. The process used may be briefly described as the "hot roller or drum process." The cooked mashed potato is spread in a thin layer on a large steam-heating revolving drum, dried and scraped off in "flakes." The "flakes" are then ground into flour. This process is sanitary and largely eliminates labor costs. While the process was developed in Europe, the American manufacturer has greatly improved the product.

It will probably be possible to prepare other vegetable flours by this process, but it cannot be applied to all vegetables. The Division of Dehydration made an unsuccessful attempt to use this process for manufacture of sweet potato flour. The sweet potato flour produced was very hygroscopic and caked in storage. Any vegetable that tends to become sticky, or gelatinous when cooked, can hardly be used by this process since the material must be cooked soft before it can be handled.

In closing, I wish to sum up in a measure the needs of the industry today. We need more investigations, especially on the technique of preparation. Products have improved this year but perfection has not been reached. Moreover, there is still a lack of uniformity in quality.

A domestic market must and will be developed for dehydrated products. This does not seem out of reach now. The individual manufacturer who is now endeavoring to establish "his brand" is indeed wise. The public will soon be calling for standard brands of dehydrated foods.

A dehydration plant must essentially have a good business organization behind it. It will be the difference between success and failure. The raw materials must be secured at a reasonable price, they must be handled properly, dehydrated properly and packed properly. A careless slipshod organization cannot do this.

The manufacturer who sits in his office and waits for some one to order his products is lost. He must go after business. Our observations have convinced us that aggressive salesmanship can dispose not only of high grade products but actually sell inferior goods. It always takes a real salesman to introduce new wares to the public.

No. 546

DEHYDRATION

By Ralph H. McKee[1], New York, N. Y.

Non-Member

IN general the American people object to having in their purchases what seems to be an undue amount of water. This is true whether the purchase is watered milk, watered stock, or canned tomatoes or peas with an undue proportion of water, and lately we have been hearing vigorous protestations because of certain new laws which require water to replace alcohol in beverages. Just about a century ago the discoveries were made which led to the present great canning industry using hermetically sealed cans and subjecting them to heat. The development of the canning industry was much helped by the introduction of tinned "cans," and greatly stimulated by the Civil War and its great requirements of preserved foods. Later cold storage developed as a real competitor of the canning industry and now we have dehydration promising to be an active competitor both of canning and of the cold storage of foods. The food requirements for the armies during the Great War have greatly stimulated dehydration.

By dehydrated foods, we mean foods where we have essentially the fresh food except that the water normally present has been largely removed. No salt, sugar, smoke, or other preservative has been added and nothing has been removed except water.

Of course, we should not expect dehydrated foods to be quickly taken up for home use. Following the past history of food changes, the first general use of dehydrated foods will probably be in institutions and armies, then in the larger civilian units such as hotels and hospitals and finally in the kitchen of the private house. Probably in no other phase of life are we as slow to make changes as in food and the methods of cooking it. More than fifteen years ago, armies began the use of dehydrated foods. Hospitals and hotels, in this city and a few others, have been using them in large amounts for three or four years and within the last few months the manufacturers of these products have been making their first efforts to

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bring them to the attention of the housewife by full page advertisements in the Saturday Evening Post.

In the United States, drying as a means of food preservation is not extensively developed. During 1915, 1916 and 1917, Canada prepared for the British Army about 44,000,000 lb. of mixed dried vegetables for use wherever England had her armies. One pound of these dried mixed vegetables is sufficient to give a nutritious soup ration to 60 men for one meal. In 1918, the U. S. Army used many thousand tons of dried vegetables. The growth of dehydration on this side of the Atlantic has been slow as compared to Europe. In Germany, there were in 1903 three dehydration plants; in 1905, 39 plants; in 1909, 199 plants; in 1914, 488 plants; in 1916, 841 plants; in 1917 about 1,900 plants, and the total quantity of potatoes dehydrated in 1917 was more than three times the total amount of potatoes grown in the United States. The U. S. potato crop is about 400,000,000 bu. annually.

There are in the United States, either working or in process of construction, nearly 30 vegetable and fruit dehydrating plants, most of them small. The method of removing the water varies somewhat, but usually a current of hot air is passed over trays of the food to be evaporated. The air is commonly heated by steam coils and blown over the trays by means of a fan. The weak points of the process are that there is no accurate control of the temperature, moisture and other factors, and in consequence, the vegetables are likely to be overheated and scorched or oxidized, or on the other hand not fully dried.

A variant of the air drying process has been developed recently in the Middle West. Air containing a considerable percentage of moisture at the beginning of the process is passed over the food. The moisture content of the air is diminished gradually as the product dries, and is so regulated that the relative moisture content of the air and products permits of evaporation of water from the product. The apparent paradox of drying with moist air is explained by the fact that moist air has a higher specific heat, that is, heat carrying capacity per cubic foot, than dry air. The products obtained by this method is said to be quite satisfactory.

In one of the Department of Agriculture Circulars (No. 126) it is stated that

"During the Boer War the British Army in South Africa was supplied with thousands of pounds of dried vegetables mixed so as to form the basis for a nutritious and quickly prepared soup. Much of this material was manufactured in Canada and shipped from Canadian or American points to South Africa. With the closing of the war, one of the manufacturers was left with several thousand pounds of such a soup mixture for which there was no local sale in the domestic markets, possibly owing to the fact that the average consumer much preferred to buy vegetables in the fresh state, and possibly because the mixture was not ideal from the standpoint of flavor and palatability. However, this material was not thrown away, but was put up in barrels which were care-

fully paraffined and stored away. After the outbreak of the European war in 1914, they were sent to the British Army and utilized in the preparation of soups just as the bulk of the lot had been used 15 years before. I cite this as an example of the keeping quality of dehydrated products, provided the conditions under which they are stored are satisfactory, and moisture and insect pests are prevented from gaining access to the food substances."

A rather extreme case is that of tomatoes. The canner normally pays about 2/3 ct. for the tomatoes in a 2 lb. can of tomatoes, a can that retails at perhaps 17 cts. The principal costs are cans, freight and processing. The same amount of tomato, if dried, will weigh less than 2 oz. One of the Department of Agriculture officials at Washington states that a carload of dried tomatoes will save the railroads from handling 30 cars of canned tomatoes, and that if all handling of lumber for boxes, tin plate, etc., is included, that 1 car of dried tomatoes gives an aggregate saving of 105 carloads of freight. This would be a very considerable saving to our overcrowded railroads.

Less than half of the vegetable and fruit crops grown in this country reach the consumer. When dehydration becomes common, a large part of these present losses will be avoided as the surpluses and second quality material will be dried. The dried product can be shipped in any weather and to any distance without excessive freight charges.

About two years ago the U. S. Army Medical Dept. requested the Harriman Research Laboratory at Roosevelt Hospital to study the methods of preserving meat. After some months Drs. Falk and Frankel developed a new laboratory method of dehydration using a method of mild heat in a vacuum. The work on the process was then transferred to the laboratories of the Department of Chemical Engineering of Columbia University where apparatus of a commercial type was available and where I took an active hand in the work. The process as finally developed is applicable to meats and fish as well as to vegetables and fruit. A vacuum shelf dryer is used, the shelves of which are heated by means of steam or hot water to a temperature too low to cause coagulation of the proteins of the food or running of the fat or oils. The food is placed in trays and these placed on the heated shelves, the door closed and the vacuum pump started. A vacuum is obtained in which water will boil at the temperature used, ordinarily a vacuum of 28 in. and a shelf temperature of about 150 deg. Fahr. The conditions used will vary somewhat depending on the food it is desired to dry. This type of apparatus is made by a number of firms in this country and abroad, and for this use requires only slight modifications in the steam connections when low pressure steam is used. The vacuum is produced by a standard type of steam-driven piston-type vacuum pump. The exhaust steam from the pump is almost sufficient to furnish that required for the vacuum oven.

The time required for dehydration varies according to the thickness of the pieces. The thinner the pieces, the more rapid is the drying. An average time is about 8 hours, i. e., three charges may be dried in the vacuum oven in 24 hours. Most materials lose 75 per cent of their weight. Meat loses 65 per cent, tomatoes and cabbage 90 per cent.

In some cases the new method gives products of no apparent improvement over the old type process, but in other cases the product is better than has hitherto been produced. A disadvantage of the process is the initial cost of the apparatus. This cost is several times that of the apparatus for drying with a current of hot air. The interest on plant investment in any dehydration process is, however, a very minor part of the cost of operation. As against this disadvantage, the cost of operation is more economical from the fuel standpoint. Only one-third as much fuel is required as when the heated air method of dehydration is used.

The new process has these additional advantages. The drying is completed in shorter time, permitting the handling of products sensitive to spoilage, such as meat and fish, and in general the product is of a more satisfactory character. Potatoes and apples are not discolored by oxidation, carrots, etc., show fewer changes in enzymes and vitamines, and no sulphur dioxide treatment of fruits is required to keep the original color. In this connection I wish to quote from an address on this same subject given in November by Dr. K. G. Falk before the New York section of the *American Chemical Society*.

"In the preservation of food, its handling, storage and transportation, first and foremost to be considered is the safety factor. Food must not be allowed to become toxic. Bacterial growth is often taken to indicate spoilage, so that prevention of such growth is of the first importance."

"Passing from and connected in a way with food spoilage, the second factor to be considered in food preservation is the question of the development of certain pathological conditions arising from the lack of chemically unknown constituents in diets apparently adequate in protein, fat, carbohydrate, mineral components. and calories. These chemically unknown constituents include the so-called vitamines, substances possessing antiscorbutic property, growth-producing property, etc., and may be classed together under the general term of food hormones. Though food hormones have only become prominent in recent years, yet their importance is evidenced by the large number of investigations at present in progress dealing with them."

"To return to the table in which the different processes were compared, the safety factor, as in all food preservation methods which are in use, is satisfactory for both dehydration methods. With regard to the question of food hormones, work is in progress with the products obtained by the two methods. From the results at present available it would appear that the foods which have been treated by the air process method result in products in which the foôd hormones are affected to various extents, and that the vacuum method gives more favorable results. This is not unexpected, as in the former method the presence of heated air might be expected to bring about more changes in the chemical and biological properties of the materials than would be the case in the latter method."

It happens that the largest amounts of materials dried have been meats. 300 lb. of meat were dried and sent to Camp Greenleaf, Ga. Last February 1,500 lb. of beef were dried for the American Committee for Relief in the Near East and sent through Constantinople to the Near East. The following extract is taken from a letter from the chief of the medical expedition of the Committee:

"I took the dehydrated beef all over Asia Minor in hot and cold, wet and dry climate conditions, and the beef seemed to keep perfectly well. Then we tried cooking it in various ways, and found it very satisfactory. We made it up into stews with vegetables, or into hash with potatoes. Most of the beef which you sent later went into the Caucasus and has helped to relieve the hunger and need in that region."

A handicap of the dehydration process as applied to meats is that it is not applicable to roasts or other thick pieces of meat. Steaks

TABLE I. COMPARISON OF VARIOUS DRYING PROCESSES

	Refrigeration	Canning	Sun Drying	Air Process Drying	Vacuum Drying
Safety Factor	O.K.	O. K.	O.K.	O. K.	O.K.
Food Hormones	Unknown	Variable	Unknown	Variable	Favorable
Transportation Facilities	Very poor	Poor	O. K.	O.K.	O.K.
Palatability	Meats—O. K. Fish—Poor	O. K.	Meats, Poor Fish, Poor Fruits, O. K.	Meats, Poor Fish, Poor Fruits, Poor Vegetables, O.K.	O. K.
Economic Considerations	Poor	O. K.	Doubtful	Favorable	Favorable

can be dehydrated, but the trouble comes in getting them to take up water in sufficient amount and it would seem that the process should not be considered for steaks, unless they are cut exceptionally thin.

We have been surprised that the fat in the meat does not become rancid. The fat of well dehydrated meat seems to keep sweet indefinitely. The reason for this may be because the bacteria require water for their growth and tests have shown that the small amount of water present is so saturated with the meat salts that bacteria do not grow and the meat, with the exception of possible surface contamination, is sterile.

In the method of drying which uses dry hot air, the effect is to dry from the surface and to bring about the formation of a compact outer surface with shrinkage of the material. The new vacuum method opens up the mass in the case of vegetables, and to a less extent in the case of meat, and this has the effect of speeding up the drying, as well as making the hydration more rapid later. Tests on vegetables have shown that the vitamines are destroyed less by this process than by the ordinary dehydration process.

One of the products which has been dehydrated in the past by a crude scheme is fish. At certain seasons of the year it is possible to dry cod and other fish in Newfoundland and in Norway by simple exposure of the fish to the sun and air. The process has not proved entirely satisfactory commercially, owing to the fact that slight changes in atmospheric conditions bring about spoilage of the material. For example, if a warm day comes, or a foggy day, or if flies or other insects appear, the fish spoils. The losses by this process are normally over 20 per cent and it should be stated that some of the remaining 80 per cent is of questionable character. By the new process fish is readily dehydrated and by putting into water, even months later, is restored to the condition of excellent fresh fish.

In time to come, cartons of dehydrated fish, meat, eggs, vegetables, and fruit will be on the housewife's shelf and will be as convenient to use as the present day can of salmon or package of crackers.

PROGRESS IN THE DEHYDRATION INDUSTRY
By C. E. Mangels
AND
DEHYDRATION, by R. H. McKee

JOINT DISCUSSION

J. E. WHITLEY: The vacuum process just spoken of, has already opened up two very interesting avenues of dehydration. I will speak first of banana drying, long experimented on, but now placed on a very satisfactory basis. The undersized bunches which are not shipped through the usual channels are in this way handled at their source. After drying in the vacuum chamber they retain flavor and color, and go as dry freight. Already an order for 1,000 lb. a week has been given to a West Indian concern by one of our largest biscuit companies and will be in operation as soon as installation is completed. A new banana biscuit will then appear on the market.

Another project is by the Ocean Leather Company of this city, which tans fish skins into a very superior article of leather. About a thousand shark skins a day are disposed of, and in addition to a liberal amount of oil from the shark livers there are at least 50 lb. of excellent meat from each shark. This is now added to the fertilizer residuum, but by the vacuum treatment it is to be put on the market as a very desirable article of diet. With the establishment of the new fishing stations in the Arctic, on the Pacific, and particularly in that head centre of "sharkdom"—the Arabian Gulf—the supply of skins and meat will be largely increased and the edible product will run into millions of pounds per year. It will then take in porpoise and whale meat which already find a ready market where they are available, particularly among our foreign born population. The vacuum process which handles meats as readily as vegetables has opened up this trade.

E V. HILL: I understood that blanching was necessary to destroy enzymes. Now why isn't it necessary in the vacuum process?

THE AUTHOR (DR. MCKEE): If we take, for example, a potato or an apple, cut the potato or the apple and allow it to stand in the air it turns black. This is due to an oxidase enzyme and air action. Now in the case of air dehydration it is necessary to treat with hot water or steam and destroy the enzyme or the potatoes will turn black; people don't want potatoes black, they want them white. In the case of vacuum dehydration, there is no air and consequently the one factor has been removed, but not the enzyme; that is, air and enzyme and potato are necessary in order to get a blackened potato; and if any of the three are removed the blackening is stopped.

E. V. HILL: I was not referring to the blackening, I was referring to the keeping qualities.

THE AUTHOR (DR. MCKEE): I did not understand Mr. Mangels to say that it was absolutely necessary for the keeping qualities. We have been working but a year and a half and we find they have kept all right for that time.

THE AUTHOR (MR. MANGELS): We have found that this action of enzymes takes place just the same after drying as before drying, and that is particularly true of cabbage, carrots and some of the common vegetables. But the changes do not take place very rapidly in some cases. I have a sample of carrots dried in vacuum which have not kept their color.

THE AUTHOR (DR. MCKEE): Our experience with carrots was, that if we kept them in the light they lost their color. We have two lots, one put in the museum container in the light, and the other in a paper carton; that in the paper carton held its color and the other did not.

THE AUTHOR (MR. MANGELS): We have some similar to Dr. McKee's (in fact, this sample dried in vacuo was submitted by Dr. McKee), which have lost color, and were kept in paper cartons in our office until some time ago when they were transferred to a glass jar. We have a number of samples of carrots which have been submitted to various conditions of storage and in all cases they will lose color in time. The same is true of cabbage.

W. H. CARRIER: In regard to the question of enzymes, the Department of Agriculture has made quite an exhaustive study of this, I understand, in connection with the curing of tobacco. The enzymes are depended upon to cause a fermentation after the tobacco is dried or cured, as it is usually termed, and during the process of fermentation, if it were not for the action of the enzymes on this dried product we would not have tobacco that is smokable. They have found that the action of the enzymes is dependent upon the moisture content. It occurs at all moisture content and at all temperatures, but it occurs very much more readily at higher moisture content and higher temperatures.

A fine quality of tobacco for cigars cannot be kept in certain climates like Porto Rico for more than a year without deteriorating so much that it is unfit for use. That is especially true of wrapper tobacco where a high quality and flavor are required.

Now this is a general law and does not apply more to tobacco than to vegetables. If, as the speaker before the last said, the article is dry enough, and kept at low enough temperature, it will keep a very long time, probably several years. The enzyme, however, will

eventually act. If there is a relatively high moisture content, the action will be very much more rapid.

I do not think the process of drying has anything to do with that, whether it is vacuum drying or air drying or sun drying. The enzyme can be killed by high temperatures and I think temperatures above 180 will kill most enzymes. Some enzymes are killed at a temperature of 140, but the oxidase and the peroxidase are killed more slowly and are not killed except at higher temperatures.

B. S. HARRISON: Dr. McKee made a statement that the primary cost in this process was the fuel cost. That is, as I understood it.

THE AUTHOR (DR. MCKEE): The raw vegetable cost and labor cost will go ahead of the fuel cost.

B. S. HARRISON: The potatoes you say were dried in vacuum and were not discolored; did I understand you to say that they could not be dried in air the same way?

THE AUTHOR (MR. MCKEE): I do not think you can dry them in air and secure the same results.

B. S. HARRISON: They can be dried in air if the humidity and temperature are properly controlled, and there will be no discoloration, no hydrolizing of the starch and no gelatinizing of the cells. It may not be so easy as in vacuum, but it can be done.

W. H. CARRIER: Would not the vitamines be destroyed at the same time that the oxidizing element would be destroyed? That is, would not some treatment to prevent discoloration destroy the other desirable properties.

THE AUTHOR (MR. MANGELS): This fundamental question has been investigated. Last year, when the Bureau had quite a large appropriation, it did some laboratory work that was misunderstood. There have been several articles published on this proposition, and in general the results have been such that we could not get anything definite out of them. For instance, an investigator goes to work and compares a fresh tomato with a dehydrated tomato. That is fair in case of the tomato; we use tomatoes fresh but there are some vegetables we never eat fresh, we always eat them cooked. That is specially true of potatoes. Now we find some of these investigators comparing fresh potatoes with dehydrated potatoes which have been blanched, of course, and they find the vitamines are less in the dehydrated potatoes. However, those comparisons should be made with cooked potatoes, as we never eat raw potatoes. That is the trouble with most of the comparisons that have been made--they have not had the right viewpoint toward the matter, and some of the work is, therefore, practically worthless.

Regarding Mr. Carrier's question, whether these vitamines are destroyed, I believe that some of these food accessories or vitamines are destroyed when the products are pre-cooked. Most of these vegetables must be cooked before they are eaten. In fact, practically all of them; so if they are going to be destroyed by the cooking what difference does it make at which point they are destroyed?

No. 547

TESTS TO DETERMINE THE EFFICIENCY OF COAL STOVES

BY JOHN R. ALLEN, PITTSBURGH, PA. (MEMBER)

and

F. B. ROWLEY, MINNEAPOLIS, MINN. (MEMBER)

IN the art of heating, many appliances have been developed by practice and accepted by long use as being built on proper lines, without regard to their efficiency or other characteristics. It is a question whether the ordinary base burner coal stove does not fall within this class. Consider the number of these stoves now manufactured and used. Where are there any tests recorded which determine their efficiency or the relative merits of the various types in use? Comparing this with the tests that have been made on boilers, for instance, we may well ask the question, "Why has not more been done along similar lines with stoves?"

There are possibly three reasons for this. *First,* the conditions surrounding the process of development; *second,* the stove is a smaller unit and efficiency is of comparatively less importance; *third,* the difficulty of determining the real output of the stove.

Recently some tests were made in the experimental laboratory of the University of Minnesota, on two base burner coal stoves. These are shown in Figs. 1 and 2, and are representative types of standard designs, each having the customary damper, drafts, gas passages and a circulating air flue, as shown in the drawings.

The heat contained in the coal burned in a stove of this type may be accounted for in three ways: *first,* the effective heat given to the room by convection and radiation; *second,* that in the unburned coal in the ash; *third,* that which passes up the stack with the flue gas. In these tests the second and third quantities were measured, the effective heat being taken as the difference between the amount supplied and that measured.

METHOD OF PERFORMING THE TESTS

In each case the stove was fired and operated for 48 hr. before the test was started. The fire was then cleaned, the ashes removed, and the magazine filled level full of coal. The test was then run

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for 48 consecutive hours, the stove being kept as near as possible to normal operating conditions. At 8 A. M. the drafts were opened, the fire cleaned, and the magazine filled with coal. Readings were taken every two hours through the day. At 10 P. M. the fire was cleaned, the drafts closed, and the check left partly open, an average condition for the night. A record was kept of all coal fired, ashes removed, of the temperatures of the flue gas throughout the setting, analysis of flue gas, temperatures of air entering and leaving the air circulating flue and the velocity through the air flue.

In the drawings, the letter T with the subscripts 1, 2, 3, etc., represents the points at which the temperatures were taken in the flues. Flue gas samples were taken at these points. The short pipe at the top of the air flues was used in order to determine the amount of air flowing through the air circulating flues.

METHOD OF DETERMINING HEAT LOST IN SMOKE STACK

The specific heat of the flue gas was determined from a volumetric chemical analysis. The weight was determined by an analysis of the coal and the analysis of the flue gas. Knowing the weight, specific heat, and temperature of the flue gas, it is a simple matter to determine the heat lost.

SPECIFIC HEAT OF FLUE GASES FOR TEST NO. 1

Average Temperature 532 deg. fahr.

Volumetric analysis	Molecular weight of flue gases	
CO_2 = 7.2 per cent x	44 =	316.8
O_2 = 12.2 per cent x	32 =	390.4
N_2 = 80.6 per cent x	28 =	2256.8
Weight of moisture,		62.0

Percentage by weight

CO_2 = 10.469 per cent
O_2 = 12.907 per cent
N_2 = 74.587 per cent
H_2O = 2.049 per cent

Average Specific heat (Langen) at 532 deg. fahr.

CO_2..........0.2128 x 0.1045 = 0.02238
O_2..........0.2165 x 0.1287 = 0.02788
N_2..........0.2475 x 0.744 = 0.1842
H_2O..........0.4705 x 0.0245 = 0.0115

Specific heat of mixture........0.24548

ANALYSIS OF COAL

	Coal as received	Oven dried
Moisture	1.61 per cent	
Ash	10.77 per cent	10.95 per cent
Sulphur	0.82 per cent	0.83 per cent
Volatile combustible matter	8.68 per cent	8.83 per cent
Fixed carbon	78.94 per cent	80.22 per cent
Hydrogen	2.41 per cent	2.45 per cent
Carbon	80.84 per cent	82.17 per cent
Nitrogen	2.51 per cent	2.56 per cent
B.t.u.	12835.5	13035.3

ANALYSIS OF ASH

Test Number	Fixed Carbon, per cent	Heating value per lb., B.t.u.
1	3.82	552.8
2	8.75	1272.0

HEAT LOSS IN FLUE GAS

Oxygen necessary to burn combustible matter in 1 lb. coal

	Molecular weight	Weight of Oxygen per lb. of substance burned, lb.
$S + O_2 = SO_2$	$32 + 2(16) = 64$	1
$2H_2 + O_2 = 2H_2O$	$4 + 32 = 36$	8
$C + O_2 = CO_2$	$12 + 32 = 44$	2⅔

Pounds of O necessary per pound of fuel as fired

S..............................	0.0082×1	$= 0.0082$
H..............................	0.0241×8	$= 0.1928$
C..............................	$0.8084 \times 2\frac{2}{3}$	$= 2.1557$
Total oxygen necessary		2.3567 lb.
Oxygen in fuel		0.0251
Oxygen to be supplied by air		2.3316

$$2.3316 \times \frac{100}{23.1} = 10.094 \text{ lb. air if there is no excess.}$$

With complete combustion and no excess air, carbon should give 20.9 per cent CO_2 by volume. The H of the fuel burns to H_2O and is condensed before the sample of gas is measured, therefore,

$$20.9 \text{ per cent} \times \frac{2.3316-0.1928}{2.3316} = 19.17 \text{ per cent.}$$

If X = the percentage of CO_2 in gas, then pounds of air supplied per pound of fuel $= 10.094 \times \frac{19.17}{x} = \frac{193.}{x}$

If we add to this the weight of combustible matter in a pound of coal as fired we have total weight of stack gas per pound of fuel $= \frac{193.0}{x} + 0.84$.

Then the heat lost in stack per pound of fuel is equal to:

$$B.t.u. = \left(\frac{193.0}{x} + 0.84\right) C_p(T_2 - T_1).$$

Where—

C_p = Specific heat of flue gas at constant pressure.
T_1 = Temperature deg. fahr. of entering air.
T_2 = Temperature deg. fahr. of stack gas.

Substituting in this equation the value obtained in Test No. 1, the B.t.u. lost in flue gas per pound of coal burned =

$$\frac{(193.0 + 0.84)\ 0.245\ (532 - 93)}{7.16} = 2913.2$$

$$\text{B.t.u. Test No. } 2 = \frac{(193.0 + 0.84)\ 0.2435\ (341-89)}{3.76} = 3163.4$$

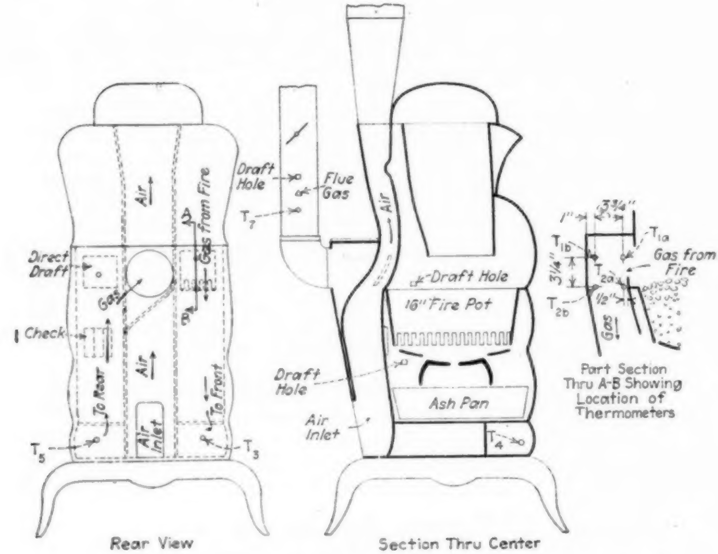

FIG. 1. A STANDARD DESIGN OF BASE BURNER COAL STOVE

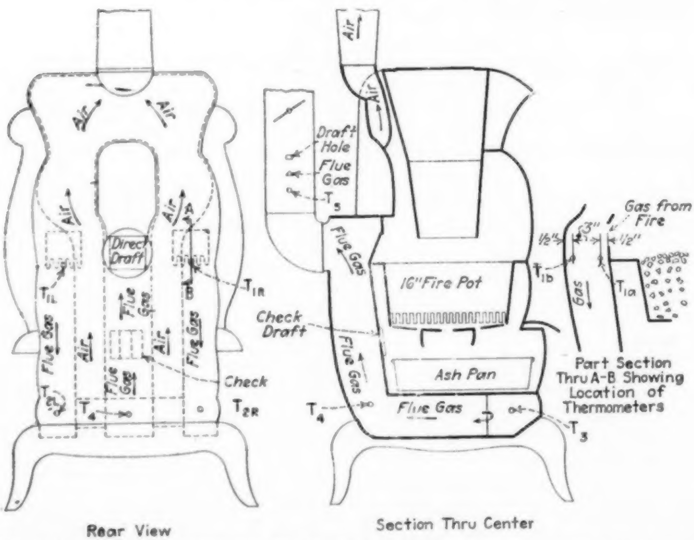

FIG. 2. ANOTHER FORM OF STANDARD DESIGN OF BASE BURNER COAL STOVE

Time	Temperatures in Stove F°									Air Flue			Draft in Water			CO_2 Stack	Dam. per pipe	Weight Lbs	
	T_{1R}		T_{1L}		T_{2R}	T_{2L}	T_3	T_4	T_5	Temp. F°		Vel. Ft. Min	Ash Pit.	Above Fire	Stack			Coal	Ash
	a	b	a	b						in	out.								
5-13-18 11.00 A.M.	1107	1170	642	717	705	575	394	450	450	95	295	312	.005	.03	.075	5.2	/		
2.00 P.M.	650	650	568	607	500	500	275	320	352	90	273	289	.01	.03	.07	4.4	/		
4.00 "	770	785	566	615	502	502	277	332	355	88	276		.01	.025	.06	4.4	/		
6.00 "	586	762	534	582	487	455	255	265	308	87	260	278	.01	.025	.03	4.1	/		
8.00 "	525	480	504	560	413	417	261		270	90	228	258	.007	.02	.035	4	/		
10.00 "	Fire cleaned and Stove closed for Night																—	26.58	
5-14-18 8.00 A.M.	Drafts opened, fire cleaned																│	11.35	4.8
10.00 "	650	750	540	610	514	435	270	280	288	95	224	255	.007	.03	.07		│		
12.00 "	710	760	572	780	575	570	355	360	382	95	240	280		.03	.06	3.5	│		
2.00 P.M.	598	610	484	550	410	420		250	290	8.7	238	262	.005	.02	.035	3.2	/		
4.00 "	455	475	420	455	328	328				87	208	231		.01	.015	2.2	/		
6.00 "	375	390	320	350		285				82	185	203			.02	2	│		
10.00 "	Fire cleaned and Stove closed for night																	37.69	
5-15-18 8.00 A.M.	Drafts opened, Fire Cleaned																		
10.00 "	750	870	580	704	510	520	300	315	370	90	278	300		.02	.05	4.6	/		
11.00 "	Fire put in condition as at Beginning of Test																	27.8	13.40
Average	652	700	521	593	494	455	298	322	341	98	246	267	.014	.024	.047	3.76	Total	103.42	18.20

FIG. 3. TEST RECORD FOR STOVE SHOWN IN FIG. 1

Time	Temperatures in Stove F°									Air Flue			Draft in Water			CO_2 Stack	Diam. per pipe	Weight Lbs.	
	T_1		T_2		T_3	T_4	T_5	T_6	T_7	Temp. F°		Vel. ft. per Min	Ash Pit.	Above Fire	Stack			Coal	Ash
	a	b	a	b						in	out								
4-19-18 10.00 A.M.	1098	918	1006	1030	666	541	510	536	488	85	295	136	.01	.04	.055	7.5	/		
12.00 "	1265	1190	1190	1272	835	685	585	637	570	97	348	158	.01	.04	.08	9.1	/		
2.00 P.M.	1252	1190	1190	1286	857	729	589	646	570	100	356	146	.01	.035	.046	7.5	/		
4.00 "	1350	1319		1330	916	730	642	661	617	98	366	150	.012	.04	.065	8.4	/		
6.00 "	1180	1255	1124	1140	822	680	570	604	560	102	356	143	.01	.035	.05	8.6	/		
8.00 "	1320	1302	1223	1260	887	726	608	652	590	103	364	143	.01	.035	.05	8.5	/		
10.00 "	Fire Cleaned and Stove Closed for Night. No Readings taken																—	44.71	3.61
4-20-18 8.00 A.M.	560	550	542	542	340	330		264	275	73	208	108	.02	.02	.04	1.8	│	22.1	
10.00 "	1116	1144	1085	1188	734	634	520	572	562	92	325	134	.01	.03	.04	8.6			
12.00 "	1100	1130	1064	1083	732	640	524	560	536	94	330	130	.01	.03	.05	6.2	/		
2.00 P.M.	1147	1020	970	1000	695	617	518	522	495	97	318	126	.01	.035	.06	5.2	/		
6.00 P.M.	943	895	902	816	618	537	422	515	475	90	325	130	.015	.025	.045	6.4	/	42.96	8.85
10.00 "	1140	988	956	1050	670	585	465	510	484	88	310	132	.01	.025	.04	6	/	15.45	2.58
4-21-18 8.00 A.M.	532	500	470	497	290	270		250	260	70	212	103	.015	.02	.03	2.2	—	24.18	4.81
10.00 A.M.	944	926	870	960	582	518	390	450	440	68	268	115	.005	.035	.04	4.0	│	18.51	2.71
Average	1155	1106	1053	1119	751	635	524	572	532	93	330	137	.01	.034	.052	7.16	Total	167.91	22.56

FIG. 4. TEST RECORD FOR STOVE SHOWN IN FIG. 2.

SUMMARY OF RESULTS OF TESTS

	Test No. 1	Test No. 2
Duration of test, hr.	48.	48.
Total coal fired, in lb.	167.91	103.42
Heating value of coal, B.t.u. per lb.	12835.	12835.
Total heat supplied, B.t.u.	2154000.	1327000.
Weight of ash, lb.	22.56	18.20
Heating value of ash, B.t.u. per lb.	552.8	1272.
Total heat in ash	12470.	23150.
CO_2 in flue gas, per cent	7.16	3.76
Temperature of flue gas, fahr.	532.	341.
Heat lost in flue gas, B.t.u. per lb of coal.	2913.2	3163.4
Total heat lost in flue gas, B.t.u.	489,000	327,000
Draft in stack, in. of water	0.052	0.047
Total heat given to air in air flue, B.t.u.	287000.	308200.
Per cent of total	13.33	23.22
Heat lost in grate, per cent	0.57	1.74
Heat lost in flue gas, per cent	22.7	24.6
Efficiency of stoves, per cent	76.73	73.66

SUMMARY OF DATA AND RESULTS

Perhaps the most interesting feature of the results obtained in these tests is the low percentage of CO_2 found in the flue gas, due to air leaks in the stove setting. The results obtained from stoves No. 1 and No. 2 as received, and after puttying up the joints, are shown in the following table. Gas samples were taken from the holes provided for the thermo-couples and the percentage of CO_2 determined.

SAMPLES FROM STOVE NO. 1

Sample Taken at	As Received	Percentage of CO_2 After Sealing Leaks
T_1	9.00	11.00
T_3	6.80	9.00
T_5	7.60	8.00
Stack	4.00	8.00

The large drop in CO_2, between T_5 and the stack in the stove as received was found to be caused by a leaky check damper. Other leaks were found in the joints between the casting of the stove due to poor puttying of joints.

SAMPLES FROM STOVE NO. 2

Sample Taken at	As Received	Percentage of CO_2 After Sealing Leaks
Leaving fire	4	10.4
Stack	2	5.2

The low percentage of CO_2 in the gas from the stove as received was found to be due principally to leaks around the doors above the fire. A lighted taper held near some of these joints showed that there was a current of air from outside to the inside. These joints were closed with asbestos putty before the test was run. After the test was over the CO_2 above the fire ran from 6 per cent to 12 per cent, depending upon the condition of fire.

GAS SAMPLE AT LOW FIRE

Sample Taken	CO_2
T_1	6.6
T_2	6.0
T_3	3.4
T_4	3.2
T_5	2.4

These samples indicate that there are leaks all along the passage, the largest being between T_2 and T_3 in the base, and between T_4 and T_5, the latter probably due to the check damper.

CONCLUSION FROM THE TESTS

These tests show that the best stoves are usually those which have the smallest lengths of cracks and seams. In some stoves there are so many cracks and seams that it is almost impossible to make them reasonably airtight. The result of the air leakage through these cracks and seams is to materially reduce the efficiency of the stove, and in the test reported in this article, it was necessary to cement the seams and cracks before satisfactory tests could be made upon the stoves. A comparison of the two brings out an interesting feature.

It will be noticed that in test No. 1 the CO_2 is high, showing a high efficiency of combustion. In test No. 2 the CO_2 is low, showing a poor state of combustion, but the actual total efficiency in the two cases is about the same. This is accounted for by the difference in the stack temperature in the two cases. In the case where the CO_2 was high the stack temperature was high, so that the benefit of the better combustion was offset by the loss at the stack. In test No. 2 the CO_2 was low and the stack temperature was low, and while we had poor combustion this poor combustion was offset by less loss at the stack.

These results go to show that in these stoves the design of the heating surface with reference to the grate surface was not as it should be and with higher rates of combustion it was impossible to get the benefits of this added efficiency because the heating surface was insufficient to remove the added heat obtained, and the result of better combustion was only to increase the stack loss.

The testing of stoves has not been taken up by this Society but there seems to be a wide field for a very profitable investigation which interests the entire public, as after all, stoves are still very widely used in house heating. From the standpoint of conservation of coal, there is a great opportunity for very profitable research along these lines.

DISCUSSION

THE AUTHOR (J. R. Allen): I do not know that the heating engineer is interested in stoves, but there are more buildings in this country heated by stoves than by any other means, so it must necessarily be interesting to the community.

When I first started to test stoves I thought a stove was a stove, but soon after I found that a stove is a sieve. There are stoves all decorated with nickel plate and isinglass windows and all that sort of thing, and every piece of decoration is another hole to let air through.

Notice the percentages of carbon-dioxide that are given in the table at the top of page 120. One is taken over the fire, two are taken through the stove and one in the chimney. No. 1 stove started

with 9 per cent of carbon-dioxide over the fire and by the time the gases reached the chimney enough air leaked through the stove to reduce the CO_2 to 4 per cent.

For the purpose of making tests we sealed it up with a cement paste and after closing the air leaks, we had 11 per cent over the fire and 8 per cent in the stack.

In the second stove, when we started there were 4 per cent of CO_2 over the fire and 2 per cent in the stack. In fact, that stove leaked air so that we could hardly keep any fire in it at all. The air all went through the cracks instead of through the fuel. It was a perfect sieve. When we had closed the air leaks with stove paste, we had 10.4 per cent over the fire and 5.2 per cent in the stack.

It shows that we should conduct more experiments on stoves; there should be experiments on the different types of stoves.

The base-burner stove is probably the worst of the stoves because it has so many isinglass windows and cracks. If we had tested a plain cast iron stove with only a few cracks we would probably have secured better results. This is a subject that is undoubtedly of interest to the public.

There is another interesting fact brought out by these tests. If reference be made to the table of results it will be noticed in test No. 1 the carbon-dioxide in the flue gases was 7.16 per cent. In test No. 2 it was 3.76 per cent. In one case we had very much better combustion conditions than in the other; there was twice as much carbon-dioxide. The last line, efficiency shows for the first stove we had 76.73 per cent efficiency and in the second stove 73.66 per cent efficiency. About as good an efficiency in one case as the other, even though the condition of combustion was very different. Now the reason for that is, that when there was good combustion in the stove so much heat went up the stack that the benefit of it was lost. With poor combustion, there was as much heat as the stove could absorb. In other words, the heating surface in this stove is so inefficient that just as good efficiency is secured from a stove with poor combustion as from a stove with good combustion, because the heat cannot be absorbed. Many stoves are designed by the pattern-maker, built and put on the market, without any knowledge of their efficiency and one of the big sources of loss of heat and corresponding loss of coal is poorly designed stoves.

No. 548

DEVELOPMENT OF THE MAGAZINE FEED DOWN DRAFT BOILER

By E. C. Molby, New York, N. Y.

Member

THE development of the down draft magazine feed boiler might be said to have begun when combustion was first recognized as combustion.

The principles of combustion are not new but are "as old as the hills." Combustion and the conditions for perfect combustion have been known but they were never taken advantage of until the advent of the down draft boiler which furnished conditions for perfect combustion never before furnished. The time has come, however, when the scarcity of fuel and the high price of fuel and labor demand that the methods of burning coal be so improved that the very highest possible efficiency be obtained. It has been known that, in order to burn coal, it is necessary to have temperature and draft. Temperature for combustion is necessary as it is only at high temperatures that the products of coal can be consumed and then only by the mixture of oxygen with these gases as they are released. Both gas and oxygen must be at a flaming temperature.

In the ordinary and better known types of boilers or furnaces, these conditions have not been taken advantage of because the fuel has been added to the combustion end of the fire. This has lowered the temperature of the combustion chamber and has destroyed the requisites of perfect combustion. Further losses in surface-fired boilers are due to exposure of the heating surfaces of the boiler to the blasts of air taken in through the fire door at firing periods, thus losing pressure and steam to secure which coal has been burned. A new quantity of coal placed on the top of this fire, as soon as it becomes heated, absorbs heat and then begins to give off gas. This gas, on account of the low temperature of the fuel itself and the fact that it is on the chimney side of the fire, is passed off through the flues of the boiler to the chimney unconsumed, and it is only when the top of the fire is thoroughly heated and becomes incandescent and after the valuable gases from the fuel have passed away, that perfect combustion is obtained.

Paper presented at Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, January, 1920.

The magazine feed type of boiler using the down draft principle of combustion was invented by John R. Surrell, an Englishman, who as a boy grew up in a district where a great deal of limestone was burned. He watched the placing of stone and fuel and its burning. It was here that the idea of the present boiler was born. Mr. Surrell, with his brother, began a series of experiments in the burning of coal and to his own thinking reached successful results. He came to the United States and after a long canvass of the boiler manufacturers, succeded in persuading a small foundry to build a boiler for experimental purposes. In 1908, he made application for letters patent on this boiler and his claims were allowed and patents issued October 27th, 1908. On July 13th, 1915, he secured a reissue of the patents.

This first boiler was only a firepot surrounded by water and with pipe connections to be connected to any steam or water boiler. This firepot was set up in front of an upright tubular boiler and tested out. The results were an evaporation of 11.09 lb. of water to a pound of coal. Analysis of the coal showed 14,500 B.t.u. per lb. Heat absorbed by the boiler was 13.645 B. t. u. per lb., an efficiency of 90.41. A number of these firepots were installed but owing to the great variation of conditions in the boilers installed, it required too large an assortment of patterns to make it commercially practical. He then built an all cast-iron boiler with self-contained firepot and placed it on the market. A great many of these boilers were installed and gave good results but the details of construction were not good and entirely new patterns and many improvements were necessary to bring them up to the best ideas of present day practice. This cast-iron boiler which Surrell brought out was tested and was found to equal the tests of his former construction in evaporation per pound of coal. (Evaporated 11 lb. of water per lb. of coal, coal containing 12,450 B. t. u.)

In the early days, Surrell brought out a round boiler, which was discontinued as it was found impractical. This boiler had a combustion chamber in the centre with a firepot extending three quarters of the way around. A fire must be of certain thickness in order to sustain itself and to do this the small boiler had too great a fire volume. The section type better meets the requirements for success in the small boiler.

The most commonly known down-draft boiler has two horizontal grates, one above the other, the upper grate being a water grate. The fire is placed on this upper grate and the draft taken from above the fire so that the draft is downward through the coal, through the fire, through the water grate, into a combustion chamber and after the fire has been worked or sliced, the burning coal and unburned coal drops to the lower grate where it burns, holding a temperature in the combustion chamber and resulting in smokeless combustion wherein there are only short smoke periods, which vary according to the manner of stoking. This type of boiler construction, known as the Hawley type, is used very generally and suc-

cessfully throughout the United States and has opened to the heating and power world vast areas of coal that otherwise could not be used except to the detriment of the health and property of the surrounding country. In this boiler, oxygen taken from above carries the smoke carbon released from the upper strata of coal downward and through the fire into the combustion chamber carrying this oxygen and smoke carbon through the fire and heating it to the required temperature, with the result that the gases and smoke carbon of the fuel are consumed. This smoke carbon is valuable as heat, and through this method of combustion renders economical results.

While this type of down-draft boiler has been of wonderful advantage, especially in power plants, the magazine feed down draft boiler embodies all of these principles of combustion and is fitted for burning both bituminous and anthracite coal; bituminous coal because it performs the same offices in smoke consuming that the Hawley boiler performs and it will burn anthracite coal applying the same principles of combustion that are applied to bituminous coal. This magazine feed down-draft boiler is one that has the water grate between the firepot and the combustion chamber and along the side of the firepot instead of horizontally above the combustion chamber as in the Hawley boiler. In this boiler the draft is taken at the side or top of the firepot, taking oxygen downward through the fire where it mixes with the escaping gases which are carried through the water grate into a combustion chamber. On account of the construction of this boiler, the water grate and the combustion chamber are always maintained at a high temperature—that is combustion temperature.

Added to this boiler is a feature of a magazine or hopper that will carry fuel for many hours firing without recoaling. Since the magazine is above the firepot, the coal feeds by gravity and as it feeds downward into a firepot which gradually widens towards the grate, the fuel is heated and the gases are released, drawn down through the fire and consumed. Whenever coal is added to this boiler, it is added at the top of the fire and not at the combustion end of the fire, hence the combustion end of the fire is always at a high temperature and the combustion chamber is at a temperature suited to combustion. In this way those first gases that are usually wasted and pass up the chimney unconsumed, are burned, the full value of the fuel is realized and high efficiency results. The fire is always carried above the tops of the gas ports or the openings in the water grate so that no air passes directly into the interior of the boiler without passing through the fire.

The boiler burns the cheaper grades of anthracite coal and burns the various grades of bituminous coal. It is recommended that only the free-burning bituminous coal be used as the firepot of this type of boiler does not lend itself to the breaking up of encrusted coal and is hard to fire with caking coal. A free-burning coal will burn to the grate but bituminous coal requires more attention in firing than anthracite and it is my belief that anthracite coal is the

better coal to use in any type of heating boiler unless it is in the home market of the bituminous variety of fuel.

The savings in fuel with the magazine feed down-draft principle of combustion are from 30 to 50 per cent over the up-draft surface-feed boiler. With anthracite coal there is required at least 50 per cent less time in attention. The drafts of this boiler can be set and a steady rate of combustion carried for hours. Stoking or adding fuel or otherwise attending the boiler does not reduce the pressure of steam nor interfere with the proper burning of the fire.

In the operation of the magazine feed down-draft boiler, I have found that in starting a fire it is best to put coal on the grate 6 or 8 in. deep, kindling broken fine, on top of the coal and to light the kindling from the top. If it is a new flue or a damp flue, the flue is heated before lighting the kindling. After the kindling is started we place coal on top of it, enough to cover the openings of the gas ports from the fire pot to the combustion chamber, and as the kindling burns away and drops down, new coal is added to keep the coal line at this higher level. This prevents the circulation of cold air through the draft door into the body of the boiler without passing through the fire. In building a fire in this way, steam is generated very quickly, and the fire is built up more quickly to the proper point. After the fire is started in this manner and the coal burned through so that there is live coal above the ports, the magazine may be filled with coal. The coal will then continue to feed down to the top of the fire by gravity. In all up-draft boilers and all magazine boilers that are not built on the down-draft principle of combustion the coal is added to the combustion end of the fire with attendant loss of fuel.

The magazine feed down-draft boilers are manufactured with adjustable magazines, so that all sizes of anthracite coal from the small sizes up to stove size can be used and are so constructed that the coal will not burn in the magazine. The magazines are on the outside of the boiler permitting easy coaling and distribution of coal. In this position they do not take up space to the exclusion of valuable heating surface. The smaller type of boiler has a magazine on one side and there is a magazine on each side in the larger size. This gives a further advantage in that either magazine can be used without the other. In the operation of a boiler with two magazines where both firepots are being used, there is a separate damper regulator operating each side. This allows the setting of one regulator at a lower pressure than the other so that as steam is generated, the drafts on one side of the boiler may be closed at a given pressure, the other side remaining open until a higher pressure is reached, and when the second regulator operates, it also operates the check damper in the smoke pipe. The smoke pipe damper to be used by hand is also furnished with a quadrant so that it may be set to control the drafts of each particular chimney. No set rule can be made for placing this direct damper. It depends entirely upon the draft developed in each individual case.

Ashes as they accumulate on the grate do not interfere with the draft, as it is taken from above. In the up-draft boiler, the draft of the boiler is being continually cut down by ash and waste accumulation. This is not the fact with a down-draft boiler. Not only does it carry fire for long hours without attention but it thoroughly consumes all the fuel and on account of its down-draft principles, clinkers are avoided, and the ash is shaken out clean. Another advantage of this construction is that it is not always necessary to clean the grate until it is free from all ash and it is therefore not necessary to shake large quantities of unburned fuel into the ashpit. The boiler with free burning bituminous coal will carry fire from eight to ten hours without attention, and we have many instances where fire is carried even longer than this with bituminous coal.

Magazine feed down-draft boilers adjust themselves better to automatic regulation or thermostatic regulation than any other boiler for when the cold nights come, the surface-feed boiler will not carry steam during the entire night without burning itself out, while the magazine feed boiler is carrying such a supply of fuel that, even if the drafts are open continuously through the night, there is fire and heat in the morning, and when the clock arrangements on the thermostat open the drafts there is a supply of coal ready and no ashes blocking the draft.

It is necessary, however, in a down-draft boiler to have a tight chimney flue of sufficient area for furnishing the proper oxygen for combustion. I have found that when a chimney is in a leaky condition the leakages in the flue itself are absorbing the entire natural draft of the flue. The down-draft boiler does not require a better flue than any boiler ought to have. By this I mean that any flue connected to any boiler ought to be a good flue. It is unfair to boiler manufacturers to place boilers on some of the existing flues and expect them to do good work.

I believe that this Society as a society and its Members individually are interested in the smaller heating apparatus placed in residences and medium structures of which there are so many thousands built each year. It is in these thousands of small homes and small buildings that the greater part of the coal is consumed and it is in these small installations that every means should be provided for economy, efficiency and sanitation. The boiler connection and the conditions under which it is set should be covered by an ordinance or laws so that conditions for economy and efficiency will be maintained, compelling conservation of fuel.

I have kept in touch with the different subjects that have been discussed here and have read the reports of the committees, and to my knowledge the question of boiler construction has never been taken up by this Society with any recommendations or with any thoughts in connection with combustion. The manufacture of boilers has been left entirely to those members who were interested in boilers and to the manufacturers who were not interested in the Society, so that the boiler constructions that have been brought out

have been brought out commercially by boiler manufacturers for the purposes of profit with the few special selling features they have been able to add to attract the notice of the engineer or the house owner. This Society should be interested in boiler construction as the boiler is the business end of the heating apparatus and without it the results of the Society investigations would be of little value. It is now time that the Society interests itself in the end of the apparatus which not only tends to a better sanitary condition of the city but also to the conservation of fuel.

In connection with the boiler and of utmost importance to the heating apparatus, is the chimney and its construction. This is a matter that can be well gone into by the Society, and the specifications of chimney flues to meet various conditions of building should be determined so that all architects, in laying out the plans for any construction, will be able to get information as to just the kind and quality of chimney that is necessary for the proper heating of the building. It is not only the boiler and the chimney for which rules should be made, but the arrangements and the local conditions on the job should also receive attention. The arrangement of dampers, the operation of dampers, the care and management of the boiler itself should receive consideration under a law compelling the conservation of fuel. The power of saving or wasting fuel is built into the building either in its perfection of detail or in its loose construction and poor specifications.

The many advantages of the magazine feed down-draft boiler, the complete burning of the largest variety of coal, the high efficiency and ease of handling, aided in the greatest conservation of both fuel and labor, make for this boiler an imperative demand upon the engineers, architects, and property owners, for recognition and for careful investigation.

I congratulate the Society on the great results already accomplished in the refinement of heating construction and equipment and I am sure that the mental energy of this Society properly placed back of this combustion principle with the greatest conservation of fuel as a goal that we shall see boiler development and construction brought up to a standard that will stand the test of centuries and be a perpetual monument to the Society and a blessing to the man who purchases coal, rendering the highest service to present and future generations.

No. 549

THE MAGAZINE FEED BOILER AND FUEL CONSERVATION

By Chas. F. Newport, Chicago, Ill.

Member

As an introduction to a discussion of the magazine, or self-feed type of heating boiler, it would be a subject of considerable interest to trace from the beginning the various attempts to apply the idea of the magazine feed to steam and hot-water heaters, and to note the various expedients by which it was proposed to overcome the different problems presented. It must suffice for the purpose of this paper, however, to state that the idea was one of the early developments in heating. The convenience, steady heating, and economy of the old fashioned base-burning stove, made the principle familiar, and it was but natural that its advantages for heating boilers should have been recognized. Many problems entered into the application, however, that were not present in the heating stove. It was found that a magazine constructed of iron or steel plates burned out quickly and that it did not serve to keep the fuel within it below the point of ignition. The magazine moreover took up space directly over the fire, and it was necessary to rearrange the heating surface. Again there was difficulty in getting a fuel bed of uniform depth to accomplish good combustion. These are a few of the more obvious difficulties that had to be overcome.

It cannot be said that any of the early designs were particularly successful although several types were manufactured and marketed. They were not sold in such quantity as to have any great effect on the trade and few of the early types are manufactured today. The item of expense was a consideration as the magazine boiler cost considerably more to manufacture.

The development of steam and hot water for heating purposes was such a tremendous advance over former methods that the ordinary design of boiler gave great satisfaction. The common types of round and sectional heaters came into general use. They were the cheapest and easiest to manufacture, found a ready market, and gave such satisfaction compared to earlier heating methods that there was no great incentive for the manufacturer to develop new ideas. The trade

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fell easily into the habit of following the line of least resistance. It is rather an extraordinary fact that in America where the science of heating has had its greatest development, while there has been great improvement in heating devices, a better understanding of piping methods arrived at, etc., the design of heating boilers has shown practically no change. Some of the earliest boilers of the surface feed type will compare favorably in evaporative power, economy, and durability, with the best the market affords today.

As competition became keen, the thought of the manufacturer was directed mostly to improvements in manufacturing methods and to cutting down costs of production. In the meantime great developments had been made in the allied field of power boilers. Efficiency that would satisfy the house owner would not satisfy the requirements of industry. Elaborate machinery for experimentation was set up by the Federal Government as well as by various educational institutions. The processes of combustion were studied, the factors that affect these processes were discovered, and the results were published. The information gained was applied to the development of new and more economical types of power furnaces. A flood of light was thrown on everything that pertains to the combustion of fuel and the utilization of the heat.

It is not going much beyond the facts to say that this great accumulation of knowledge remained for the heating boiler field, practically a closed book. The makers of heating boilers still continued to follow "the easiest way."

The magazine feed idea was never without a few adherents and some models were developed that were a great improvement over the earlier types. But that the principles which make power boilers efficient might be applied to heating boilers by means of the magazine feed device, was an idea of strangely slow growth. Even today there is a decided lack of recognition of the principles on which the magazine heater obtains its results.

Let us examine some of the laws that have been proved to be correct in power practice which may be applied to the heating boiler. I quote from Bulletin No. 334 of the United States Geological Survey:

> All the authorities on the subject of combustion and smoke prevention agree*** caol should be supplied to the furnace in small quantities at frequent intervals. The more nearly the fuel approaches a continuous and uniform supply the better the results.

It is axiomatic to say that economy depends on good combustion, and from the magazine boiler man's standpoint the surface feed heater violates all the rules of good combustion. I quote again from the same Bulletin:

> The hand firing of plain furnaces violates all the principles laid down for securing good combustion. The coal is usually supplied in large quantities at long intervals, and the result is that at the times of firing the temperature of the furnace is lowered, the resistance to the flow of air through the fuel bed is increased, and consequently great quantities of combustible gas are

generated which cannot be burned for lack of air and the necessary amount of heat.

Heating boilers must, of necessity, receive infrequent attention, and the only way that a fairly long firing period can be obtained by the hand-firing method is by piling a great charge of fuel on the grates. The new fuel absorbs the heat from the fire and for the time being heat production is absolutely stopped, as evidenced by the drop in steam pressure or the fall of temperature of the water. While the processes of combustion are striving to reassert themselves, large amounts of combustible gases are passing up the flue unburned. I quote from Technical Paper No. 97 of the United States Bureau of Mines:

> When heavy firings are made, the fresh fuel not only increases the resistance to the flow of air through the fuel bed, so that the rate of combustion is lowered, but it acts as a cold blanket to screen the heating surfaces from the radiant heat of the fuel bed.

In the magazine feed boiler, on the contrary, the feeding of the fuel is gradual. The volatile gases as they are distilled, must pass through the high temperature of the fire box and over the incandescent fuel. They are completely consumed and in the case of bituminous coal the result is practically a smokeless boiler. The carbon of the fuel is brought to the incandescent stage under circumstances favorable to its perfect combustion.

No efficient power boiler uses a thick fuel bed. Here again, in the magazine boiler man's opinion, the surface feed boiler violates all the canons. The fuel charge necessary for a fairly long firing period must be piled thickly on the grate of a surface feed boiler and the entire mass of fuel must be under combustion at the same time, regardless of the amount of heat desired. These conditions absolutely prevent the mixture of air with the hot gases which is necessary for proper combustion. It must be kept in mind that the magazine boiler has only a fraction of its total fuel capacity under combustion at one time, the proportion varying with the type of heater. The heat from this smaller amount of fuel can be developed with a completeness that is far in advance of what has been the practice in heating boilers.

Technical Paper No. 97 above quoted, says also: "Keep the fuel bed uniformly thick but not too thick," and this is the law of the magazine boiler. The fuel bed depth in a properly designed magazine boiler is of the uniform thickness which accomplishes an even combustion all over the grate. An even combustion cannot occur where fuel is heaped up.

The various bodies of engineers that were called together by the Government during the war to prepare instructions for the economical burning of coal in heating plants agreed, without exception, on two points:

1st. Fuel must be fed on to the fire gradually and not thrown on in large amounts.

2nd. The fuel bed must be of uniform thickness.

Both of these requirements are met by the properly designed magazine boiler.

It was suggested that in the preparation of this paper the subject of magazine heaters be treated with especial reference to the question of fuel conservation and the utilization of cheap fuel which is not practicable for use in the ordinary type of heater.

I have shown how the magazine heater is a conserver of fuel because of the economy gained by following the laws for good combustion. Now I will turn to the question of cheap or by-product fuel.

Anthracite coal is particularly well adapted for heating boilers, and for domestic use its cleanliness, its slow-burning properties, and its freedom from smoke, make it especially desirable.

Anthracite is so hard and dense that air does not penetrate it and therefore it burns only on the surface of the lumps. Thus the finer the coal, the greater is the total area of the surfaces and the more rapidly it can be burned. Also its tendency to pack is greater so that fire can be held in a banked condition for hours with very little loss of heat from the fuel.

Anthracite is graded to size and the price is based on these grades. Table 1 indicates the relative sizes:

TABLE 1. SIZES OF ANTHRACITE COAL

Size	Through screen with mesh, in.	Over screen with mesh, in.
Furnace		2¾
Egg	2¾	2
Stove	2	1¼
Chestnut	1¼	¾
Pea	¾	½
No. 1 Buckwheat	½	¼

Many analyses of coals in the government buildings show that anthracite as usually delivered, contains about 4 or 5 per cent moisture, 2 or 3 per cent volatile combustible matter, 75 to 80 per cent fixed carbon, and 8 per cent or more of ash, according to the size and quality. During one season the various sizes delivered to government buildings averaged about as follows:

	Ash in dry coal, per cent	B.t.u. in coal as received per lb.	Million B.t.u. per Ton	Cost of one million B.t.u. @ $1.00 per ton, in cents.
Furnace and Egg	10½	12.800	25.6	3.90234
Pea	15½	12,000	24.0	4.1666
Buckwheat	18	11,500	23.0	4.348

The smaller sizes of anthracite have nearly the same heating value as the larger sizes and they are much cheaper. It will be seen from the above figures and a little study of hard-coal prices that the use of large sizes of anthracite is expensive when compared with the possibilities attainable with small sizes. The buckwheat size may in many places be purchased for $3.00 less per ton than is charged for the larger size coal. Prices quoted in Chicago this winter are

$10.00 per ton for No. 1 buckwheat and $13.00 per ton for stove and egg sizes.

At these prices, it costs 16½ per cent more to burn the larger sizes than No. 1 buckwheat, where the same boiler efficiency applies. In the West and Northwest country that is supplied with anthracite through the lake ports, most of the buckwheat coal sold is what is known as "dock" buckwheat, that is, screened at the docks from the coal shipped in lake boats. This is much higher in heat value than the buckwheat made at the mines—in fact it often runs higher in B. t. u. and less in ash than some of the larger sizes and is an excellent fuel.

During the war, the hard coal fuel restrictions did not apply to buckwheat coal and it was therefore as easily obtainable as soft coal. In fact last fall and winter there was a surplus of this size in Chicago, a soft coal district.

The conditions for the successful burning of small sizes of anthracite are not found in most heating boilers unless they were originally designed for this purpose. It is practically impossible to burn buckwheat anthracite in the surface feed boiler, even though grate bars with small openings be installed, on account of the depth of fuel bed on the grates necessary for proper combustion. This fuel bed cannot exceed 8 in. in thickness without excessive draft requirements to force the air through the small pieces of coal which lie closely together. Thus in a surface feed boiler with a firing period of 8 hours with a 16 in. fuel depth, the firing period would be decreased to between 2 and 3 hours when burning buckwheat coal, a very impracticable boiler for most heating purposes.

It has been found that the most practicable and successful method of obtaining a long firing period in burning the smaller sizes of anthracite in a heating boiler is feeding the coal into the fire-box from a magazine onto a sloping grate that will give a uniform fuel depth for proper combustion.

The magazine should be of ample capacity so that re-coaling will not be necessary more than once in 12 hours as a minimum, and so situated that it can easily be charged with coal, and so that it does not affect the amount or sensitiveness of heat absorbing surface. The throat of the magazine should be as narrow as consistent for proper feeding of the coal, and water cooled for durability as well as to prevent the coal from burning and caking in the throat. The distance between the bottom of the throat and the grate will determine the depth of fuel on the grate, which should not be over 8 in. for buckwheat coal, but should be increased if larger coal is to be burned.

The grate should slope down from the throat of the magazine in such a position as will determine an "angle of repose" so that there will always be a uniform depth of fuel over the entire grate. The grate bars should be provided with openings as large as practicable and yet prevent loss of fuel through them into the ash-pit. The

grate should be arranged so that the lower part can be cleaned more thoroughly than the upper part on account of a greater accumulation of ash along the lower side.

It is well to provide some method of supplying moisture to the ash-pit, either in the form of a steam-jet or a water-spray, both as an aid to combustion and to prevent the formation of clinkers on the grate when running under a high rate of combustion.

When these requirements are met it is perfectly feasible to secure a feeding down of the fuel that will deliver steady heat for twelve hours in cold weather. In mild weather this period will be considerably lengthened.

It is a common experience that the smaller the size of fuel that can be used in any heater from a stove up, the greater the economy. Technical Paper No. 97 of the Bureau of Mines says: "Use small sizes of coal if they are available and the draft is strong enough. However in many furnaces a less amount of the small sizes appears to give the same effect."

This is exactly the case with the magazine heater. The saving from the use of buckwheat coal is in reality greater than the 16½ per cent represented by the difference in actual cost as in the case previously cited. This is due to the perfection with which the heat from the gradual and complete combustion of this fuel can be utilized.

The fuels which can be used in the self-feed type of heater are practically limited only by the necessity that they be sized. Proper feeding and good combustion cannot be obtained with unsized fuel. Anthracite, non-caking bituminous, coke and even lignite are all being used at the present time. Obviously it is necessary to avoid the large sizes, although up to stove or range, anthracite can be used with marked economy.

Although the great emphasis at the present time is on the conservation of fuel, much might be said on the conservation of labor. The scarcity and price of labor constantly increase. Here, also, the magazine heater affects a material saving. It is not an exaggeration to say that with a properly designed boiler of this type the labor of operation may be reduced by as much as 75 per cent.

Beside the economy in fuel and labor, the point that most interests the house owner is the steadiness with which heat can be delivered. The gradual consumption of fuel, the small amount under combustion at one time, and the accuracy with which this smaller amount can be controlled by automatic regulation, make the magazine heater of especial value for this purpose.

There is every indication that we are at the beginning of a new era in heating. New standards of heating comfort are demanded as well as new standards in economy of fuel and labor. As these ideas develop we may confidently expect a growing interest in the magazine type of heater.

THE MAGAZINE FEED BOILER AND FUEL CONSERVATION, by Charles F. Newport,

AND

DEVELOPMENT OF THE DOWN-DRAFT MAGAZINE FEED BOILER, by Edgar C. Molby.

JOINT DISCUSSION

P. M. Beecher: It should first be stated that to the manufacturers of this type of boiler, as well as of any other type of boiler, the chimney is most important. My company does not accept an order for a boiler of this type unless there is in our possession a data sheet giving us full information in reference to the amount of radiation that is to be attached to the boiler, the size and height of the chimney, as well as the quality of coal to be used.

I found when I first made a boiler of this type that, by not having in my possession the above information, the boiler was apt to be installed under unfavorable conditions, which entailed considerable expense to the company. I remember, and Mr. Molby will undoubtedly remember also, that in the installation of one of the first boilers of this type sold, after it had been installed, we found that the fitter had connected it to a flue 4 x 20 in., and as the owner refused to build a new flue this necessitated removing the boiler at quite an expense and gave this particular style of magazine feed boiler a "black-eye" in that locality.

I would like to see this Society take up the question of the proper size flues to which different capacities of boilers should be attached. I am no engineer and I cannot tell you how to do it; my experience has been in trying to sell the apparatus that some engineer invented.

Homer Addams: There is no question that about two-thirds of the anthracite fuel, of which there are about 60,000,000 tons mined, is probably burned for domestic use. At the price prevailing today that means possibly $4,000,000,000 for anthracite coal. As I see the ashes that are taken out of my own place weekly and the carelessness in the handling of the fires, more and more I feel that something should be done to get the ashes to powder, to prevent clinkering. I believe that this type of construction for the average small apparatus is one step toward that end.

I was wondering, when I heard Mr. Beecher, what he had done as a boiler manufacturer to prevent that man from putting the boiler upon that 20 in. by 4 in. flue. Does the boiler manufacturer tell the man that sells the boiler in the catalogue in which he gives the rating, that he ought to have a certain height flue to carry certain loads? The matter of power, the matter of developing more capacity, is a matter of more chimney very often.

E. R. TROXELL[1]: It is very important that the manufacturer should absolutely know the conditions that will surround the installation of a boiler, before it is sold. It is safe to say that 90 per cent of the trouble in the field of magazine feed boilers is due to inadequate draft; not only to lack of proper chimney area, but to poorly built chimneys—leaky chimneys. Architects are not always careful to specify the breaking of joints in the tile lining of the flues. Drawings often show several flues in the same chimney breast butted right up against each other and you must remember that the ordinary bricklayer is not interested in making each flue smoke-tight. He generally carries up the outside wall of the chimney a short distance, sets in a length of tile for each flue, throws a few brick bats around them, and repeats the operation. The result is a very leaky chimney and waste of fuel no matter what class of boiler is used. To test such a flue we usually build a smoky fire in the boiler and plug up the top of the boiler flue. If the smoke leaks out of fire places and up adjoining flues a magazine feed boiler should not be used and, for reasons of economy, the chimney should be rebuilt. It is rather a hopeless condition to remedy otherwise.

I very well remember showing such a chimney to a well-known architect in this city. This chimney was a pet feature of the house, to his way of thinking. It had a little window through it and was very artistic, but it leaked like a sieve, would not hold any vacuum at all, consequently would not draw, and the owner had to resort to burning one of the larger grades of fuel, or else tear the chimney down and rebuild it. From that day to this that architect specifies bell and spigot pipe for the boiler flues; bell end up, sealed with cement mortar. He said he would never have a leaky flue again and I don't think he will.

I do not want to say anything about the design of magazine feed boilers, having always been concerned merely with the selling of them and keeping them sold. A man who wants to handle boilers of this kind has got to conduct more or less of a campaign of education. Anybody can get some kind of results from a surface feed boiler, because it is simple enough to shake the grates and "fire up." The man who "fires up" a magazine feed boiler generally gets himself into trouble unless he knows how to go about it. It is very easy to fuse the smaller sizes of coal together but at the same time there are very good ways to avoid a large percentage of clinker, or get rid of it even after it is formed. The layman doesn't know how and it is sometimes hard to educate him in the proper handling of a fire under these conditions.

Therefore, it is up to the manufacturer to go a step further than simply seeing that the flue is of the proper size and that the boiler is of sufficient capacity to take care of the load. I think he ought to establish a service department to help people properly burn anthracite coal, or bituminous, as the case may be, after the boiler is installed.

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[1] Spencer Heater Company, 101 Park Avenue, New York, N. Y.

It is a mistake for the manufacturer of a magazine feed boiler to think that the man to whom he sells is necessarily going to save fuel. People are apt to go as far wrong with a magazine feed boiler as with any other boiler. There is a good deal for the layman to learn about the proper firing of any boiler and it is the many thousand amateur firemen who are wasting a large percentage of our annual coal supply. A magazine feed boiler will quickly show up a leaky, wasteful flue, but there are a number of tricks to be learned about firing even with this feature. I therefore think this question of educational service, especially by the magazine boiler manufacturer, is well worth considering.

E. A. May: In obtaining that 90 per cent of efficiency obtained in the boiler, what was the temperature of the escaping gases? It would make it more clear if the author would specify whether he means evaporation per pound of actual coal, as he states in his paper, or per pound of combustible, ash and moisture free. It is rather difficult to know on just what basis he has calculated when he says per pound of coal.

T. Barwick: I have used most of the different types of down-draft boilers and also magazine boilers in my practice. The trouble has been in most cases the fault of the flue. The reason for that, is that some of these boilers have been connected to flues that were not of proper size and of proper draft. There is no reason why a down draft or even a magazine type of boiler should not do as well as the surface burning boiler, as long as there is a proper draft to pass through.

I have used the down-draft boiler in places where there has been too small and too light a draft. Where there is very low draft efficiency there will be trouble. In one building in Yonkers, I replaced a down-draft boiler. It was second-hand, purchased by the owner, and we had trouble. We did not get the efficiency from it for there was only a 25 or 30 ft. flue; we would have to have with that particular boiler a draft to equal a chimney 80 or 90 ft. high.

I have generally recommended magazine boilers only in cases where the flues were of ample size and of ample height. You can't get air down through the bed of coal unless there is draft power, unless the chimney is all right. Moreover, it is not wise to place the setting of a boiler in the hands of an incompetent man; the owner or the seller ought to know exactly the conditions under which this boiler is to be run.

E. F. Hammel[1]: I want to congratulate the writers of these papers on their presentation of the case, and I am led to speak because of the criticism which has been made of the chimney flue. I want to suggest that perhaps you gentlemen are somewhat at fault in not telling the architect what size flue he ought to put in. Architects have got a great deal to do in designing a large building, and a chimney by them is regarded as more of an architectural detail,

[1] Engineering Editor, The American Architect, 243 West 39th St., New York, N. Y.

perhaps, than as an engineering feature and a necessary adjunct to the proper functioning of the heating apparatus. First there is the design of the radiation and after following the information that Prof. Allen has been giving us about variable constants, it is really a wonder that we ever get the proper amount of radiation in a building. Next we must find the proper size boiler to fit the radiation. Usually we go to the boiler maker and find out the size of boiler rated to carry the load and then get one a little bigger and figure it will work all right; then we must fit the flue to the boiler. Now there is the three-fold combination, and to get the proper effect from it and get the whole thing operating right is something of a difficulty. It seems to me that this body of engineers, probably the largest and most important body of heating experts in the country, owes it to the architectural profession to tell them from a scientific standpoint what size flue and what size pipe they should have to satisfactorily meet the varying conditions encountered in practice.

I want to say as associate editor of an architectural publication that I would be only too glad to give all the publicity to that kind of information that is necessary. I am sure the architects would be glad to have it.

The city ordinances governing chimney construction do not help solve the problem, since such ordinances are designed, as you know, almost entirely from the fire hazard standpoint; probably the only reason that city codes require flue lining is to have less danger from fires. Thus the rules for the construction of chimneys, such as there are in the city, are not comprehensive from the viewpoint of getting a proper draft. Undoubtedly we must also have a flue which is not a fire hazard in the building, and there is no reason why such ordinances should not be broadened in their scope so as to specify proper sized flues for the heating. There was recently made in New York City a revision of the Sanitary Code by the Health Department, which makes it obligatory upon landlords to furnish tenants a certain amount of heat, that is, in residences. The law simply says there must be a certain temperature maintained in cold weather. Now if the law goes that far it seems to me it might go a little farther and see that a proper sized flue is put in a building so that the amount of heat that is necessary can be gotten out of the boiler. I don't know of any reason why an organization of this character should not conduct some active work in trying to get architects to specify proper sized flues. We have ordinances governing plumbing work.

One cannot in plumbing install an improper size pipe without getting into trouble right away, and it seems to me the heating of a building is just as much a matter of public health and comfort as the size of plumbing pipes in a building. If you gentlemen will furnish the architects the scientific data on the construction of chimney flues they will be only too glad to take them and use them and thank you for them.

THE PRESIDENT: Truly, we are seeing the wisdom of forming our Bureau of Research. It would be a comparatively simple matter for the Bureau of Research to take up this question of chimney flues, to report upon the size of flues desirable and necessary for buildings of different character, upon flues for residence properties, in which most of these magazine boilers referred to tonight are to be found. Mr. Hammell has rendered a decided service to this Society, and perhaps to the architectural profession, in calling our attention to the fact that we can supply these data and that they will be well received.

Mr. Molby referred to our dereliction of duty in not designing boilers. Of course there are a number of the members of this Society who are capable of designing boilers but it is scarcely a function of the Society to design boilers. It may be, however, that the Society, through some of its activities, can indicate some of the requirements of a boiler. I would like to say that so far as domestic boilers are concerned there is one feature of a boiler which should receive attention, and that is means for cleaning the boiler. Perhaps there is no greater improvement required in the design of boilers than to provide adequate, simple means for cleaning during the operation of the boiler, so as not to shut it down during the process. The majority of the heating apparatus in existence runs from season to season without cleaning. It is not all due to carelessness. Most of it is due to the fact that adequate provision has not been made for cleaning the surface of the boiler.

P. J. DOUGHERTY: I am very much interested in this discussion of the magazine boiler by its leading representatives. My 12 to 15 years' active experience with this so-called "razor-back" grate boiler, as a heating contractor and sales manager, warrant a close and searching analysis of the real merits of this type of magazine boiler.

The principal representatives of this boiler very wisely emphasize the importance of a service department to make each sale stay sold, due to special requirements of coal, draft and methods of firing. Those requirements are so exacting that it has been said that with each magazine boiler should be furnished a fan or blower to produce suitable draft, a clean grade of buckwheat coal of the right size and an expert fireman. The surface feed boiler salesmen have an occasional trouble job. The magazine boiler sales that do not turn out trouble jobs are few and far between. This continued diet of trouble jobs eats up the contractor's profits on the job, hence he as a rule fights shy of this type of boiler. The cost of this service is a close second to the cost of manufacture which the owner pays for when he pays the high price demanded for the magazine boiler.

There are no engineering data on magazine boilers submitted in support of the arguments advanced in this article. Several quotations from Government bulletins, principally on power boilers are submitted.

The remarks as stated about heavy firing and keeping the fuel bed not too thick, apply as set forth in the original to "when the demand for heat is urgent or the fire must be built up quickly."

As regards the proper thickness of fuel bed in heating boilers this same Technical Paper No. 97 states: "If the full rated load is to be carried without attention to the fire for a minimum period of 8 hours, the depth of fuel bed should be at least 12 in. A heater that is to burn coke should be designed for a greater depth—probably 24 in. In fact, one of the largest manufacturers of boilers for heating houses by steam or hot water now designs such equipment for a fuel bed of 18 in. deep when anthracite is used."

A thin firebed of 4 to 8 in. is good practice in power boilers for proper combustion conditions and reduction of clinker formation as set forth in Technical Paper No. 205: "A thick fire and accumulation of clinker on the grates may cause stack losses because of the large excess of air. It is well to add that thick fires are the most common cause of troublesome clinkers." The very opposite is true in heating boiler practice as set forth in Technical Paper No. 242: "If the size of the furnace will permit, the fuel bed should be carried 18 in. thick. A thick fuel bed helps to check the draft and gives slow, uniform combustion and uniform temperature in the house. With a thick fuel bed the fire will last a long time without attention. If a thin fuel bed is carried, the coke burns too fast giving a hot, uneven fire that burns out quickly and requires frequent firing. A thin fire also tends to produce more clinkers."

As indicated in those Government bulletins, whatever is true in power practice, the very opposite as a rule is true in heating boiler practice. In power practice we have high presssures; high draft intensities, high rates of combustion, high firebox temperatures, short firing periods, small fuel charges, thin firebeds, trained men usually in charge, etc. In heating boiler practice we find the very opposites: low pressures, low draft intensities, low rates of combustion, relatively low firebox temperatures, long firing periods, large fuel charges, thick fuel beds, untrained men usually in charge of the boiler, etc.

There is no comparison between the magazine feed principle of a heating boiler and a power boiler's automatic stoker which not only feeds the coal to the fire gradually and positively, but what is just as important, the stoker also removes the ash and clinker as they are formed. The magazine principle will continue a laboratory appliance where coal, draft and firing conditions can be made as nearly perfect as possible, until some provision is made to automatically remove, like the power boiler stoker, the ash and clinker as they are formed, and thus prevent them from choking off draft, reducing effective grate surface, causing chimney trouble, producing poor combustion conditions, and preventing the coal from feeding uniformly. Such are the facts of the case gleaned from long years of close study and trying experiences.

According to my experience of 20 years in firing and testing various types of heating boilers, when the ordinary 20 per cent of fire is left on the grates and with an ordinary draft, it is best practice to shovel 50 to 80 per cent of the full charge on the fire the first firing, leaving part of the red coals exposed to burn the gases. In about 15 to 20 minutes the balance of the full charge of coal can be put on the fire, bringing the top of fire up within 6 in. of the crown sheet of flat grate boiler using stove coal. Facts demonstrated to be correct in research and practice take precedence over what the books or authorities may say.

No data are given to prove such advantages for the magazine boiler as a saving in labor "as much as 75 per cent," a saving in fuel "greater than 16½ per cent," a "greater steadiness with which heat can be delivered," and a more "perfect combustion" of the fuel.

What are the facts of the case? If as stated, "It is axiomatic to say that economy depends upon good combustion" why is it the records show an efficiency of 9 to 10 lb. of steam per pound of fuel for surface feed boilers and less than 9 lb. of steam for magazine boilers per lb. of fuel? The combustion conditions are so poor in magazine boilers that the magazine and fire doors must be hung loose without catches, as on gas automatic water heaters, to relieve the pressure by the customary gas explosions from doing considerable damage.

The saving of "75 per cent of the labor" applies only to the older designs of surface feed boilers rated on a 4 to 6 hour basis, due to their shallow firebed of only 10 to 14 in. The recently designed surface feed boilers with their 16 to 20 in. of firebed are rated on an 8, 10 and 12 hour firing basis. When the trade figure their surface feed boiler capacity on a 10 to 12 hour firing basis as residence conditions demand, the surface feed boiler will have silenced the principal thunder of the magazine boiler salesman. The magazine boiler that will run for 10 to 12 hours without shaking of the grates once or twice during the day is the exception, not the rule.

The draft resistance through a magazine boiler fuel bed keeps continually increasing, because the depth of the fire remains the same, but the density of the firebed keeps getting greater and greater, due to the close packing of the fine ash and clinker by the head of coal in the magazine. The draft resistance through a deep 15 to 20 in. bed of stove coal changes but little during a 12 hour firing period, due to the fact that the decrease in resistance, due to the fire bed getting thinner and thinner, is partly offset by the increase in density due to the accumulation of ash. As a rule the resistance is slightly less through the fuel bed of a surface feed boiler at the end of a 12-hour firing period than at the beginning. It is evident the resistance through the magazine fuel bed keeps continually increasing, hence the usual draft trouble and, as a rule, the necessity for shaking the magazine boiler grates to break up the packed bed of ash and clinker after the fire has been burning a short time.

The facts of the case do not bear out the saving of 16½ per cent in fuel, let alone the stereotyped claim of 30 to 50 per cent. Before the war I made a rather extensive investigation of this matter in high-class residences, heated by vapor, located in Evanston and Lake Forest, north of Chicago. With buckwheat coal at $5.50 as used by the magazine boiler, and stove coal at $8.25 as used in the surface feed boiler, the cost of heating with the magazine boiler averaged 14 cts. against that of the surface feed boiler of 10 cts. per sq. ft. of equivalent direct steam per heating season in both cases. The magazine boiler averaged one ton of buckwheat per season for each 40 sq. ft. of equivalent direct steam radiation, while the surface feed boiler averaged one ton of stove per season for each 80 sq. ft. of equivalent direct steam radiation. The proof of the pudding is in the eating.

This high coal consumption of the magazine boiler is due principally to the following causes: As a rule, buckwheat contains two to four times the amount of ash that stove coal does. So much unburnt coal passes through the razor-back grate that its ash pile after a shower looks more like a coal pile. It requires a forced draft to economically burn a bed of 8-in. of small buckwheat coal on grates, hence because of unfavorable draft conditions, a magazine boiler salesman soon becomes expert in dodging carbon monoxide flames shooting out through fire doors after firing fresh coal. Under such conditions the best part of the fuel passes up the chimney as unconsumed gases, the heater acting as a gas producer instead of a heat producer. Excess air, due to high ash content of coal, and white spots on grates after fire has run a few hours, as indicated by test records showing only 6 to 8 per cent carbon dioxide, mean high coal consumption.

Technical Paper No. 97 states: "Unquestionably with any fuel, the prime factor for determining fuel consumption and freedom from operating trouble, although it may generally not be recognized, is method of operation." Such being the case, it is quite evident why a service department is such a prime factor in making expert firemen, which the magazine boiler demands. According to firing instructions in magazine boiler catalogs the magazine boiler should be fired like a power boiler by pushing the red coals from one part of grate to the other in order to dump the ash and clinker. That is a job for a regular stoker which the average janitor will pass up, let alone the average house-owner. As a result, the grates must be shaken oftener and the ash pile looks more like a coal pile.

In my time, I have replaced dozens of surface feed boilers with magazine boilers, and often materially reduced the coal bills as well as materially increasing them. I have also replaced magazine boilers with surface feed boilers and practically cut the coal bill in two. I can't recall a single instance where the magazine boiler deserved the credit itself for the fuel saving. There are 101 conditions about a heating plant besides the boiler itself that cause high coal bills.

In 99 per cent of the cases, however, the buck is passed to the boiler. The remedying of those adverse conditions when installing the magazine boiler is the real cause of reduction in fuel cost. Any of the following conditions increase coal bills; unfavorable draft, or draft control, improper quality or size of coal, improper firing, dirty boiler, improperly cemented boiler between sections, faulty piping, faulty radiation, improper type or size of boiler, faulty smoke-pipe, etc.

Testimonials have little or no engineering value, any more so than any medicinal value where they reign supreme. The general run of magazine boiler literature will not stand very close engineering scrutiny. As an example Fig. 1 is taken from a magazine boiler catalog, to convince the unsophisticated what rank combustion conditions exist in the surface feed boiler. That illustration showing the entire fire smothered, is as unjust a presentation of the proper

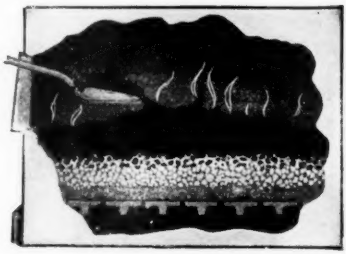

FIG 1. THE WRONG WAY TO FIRE A SURFACE FEED BOILER.

method of firing a surface feed boiler as if the surface feed catalog should produce a cut of a magazine boiler with a flat fire on the grates instead of a sloping fire as it should be. Fig. 2 showing part of the red coal exposed to burn the gases, and with 50 to 80 per cent of the total fuel charge put on the first time, is the proper way to fire a surface feed boiler.

It can be truthfully stated that for steadiness of heat, for economy of fuel, economy of attention, and practicability of design to meet the average requirements of fuel, draft and firing conditions, the modern surface feed boiler stands without a peer in the heating boiler line. The magazine boiler is designed along power lines to burn power size coal and should be operated under power conditions as regards forced draft and high pressure stoking conditions of removing the ash frequently from the grates.

The Author (C. F. Newport): I want to say that when I was asked to prepare this paper the time was very short and I did not have much time for preparation. I was, however, asked to prepare a paper that would bring out a discussion on the subject, and I think I have done so.

Mr. Dougherty refers to the difference between power boilers and heating boilers; but he does say that the underlying principles of combustion agree on both power and heating boilers; in other words, the standards of combustion are the same, as he put it.

P. J. DOUGHERTY: The principles, Mr. Newport, are the same.

THE AUTHOR (MR. NEWPORT): I think you also made a statement of the standards.

P. J. DOUGHERTY: The standards of practice are radically different.

THE AUTHOR (C. F. NEWPORT): By admitting the underlying principles to be the same, I do not see that there is very much of an argument there. At any rate, I claim that the magazine feed feature more nearly approaches the efficient power boiler principle of opera-

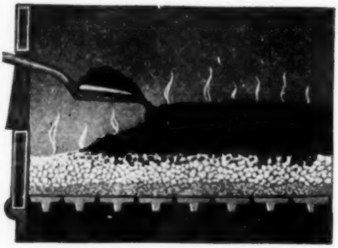

FIG. 2. THE RIGHT WAY TO FIRE A SURFACE FEED BOILER

tion than the surface feed boiler. That is the reason for using the quotations in question.

In speaking of the thick fuel bed, reference was made to coke, while I was referring to coal. We all know that a much thicker fuel bed must be carried for coke than for coal.

The question of chimneys was brought up, and I am very glad that it was, because nine-tenths of the boiler manufacturers' troubles, I think, are due to insufficient draft resulting from poorly constructed chimneys. When we started out during the war on this fuel conservation question, I think we went at it from the wrong end. The first year of the war in France, on account of the scarcity of fuel, they sent out a corps of experts that examined every flue in the country to which a fuel burning apparatus was connected. In other words, they realized the value of a good draft to produce good combustion—hence fuel conservation. Nine-tenths of the troubles of chimneys, I find are not so much in the size or height of the flue as in a leaky flue. I have cured many a draft condition by stopping the leaks in the flue. One thing that the architects and builders should have impressed upon them most strongly is to build an absolutely tight flue.

F. B. Howell: It is obvious in this study that the nature and the use of the buildings taking such installations as residences, apartments, blocks, hotels, churches, schools, etc., must be kept in mind, because of the time periods between cleaning fire and re-coaling which essentially occur in such buildings owing to other intervening duties of the attendants. Of greater import is the consideration of the kind of fuel intended to be burned in these two unlike types of boilers. With anthracite rapidly diminishing, and with bituminous, coke and lignite constituting the country's coal fuel of the very near future, it would appear that the behavior of the latter fuels in a magazine and in a surface burning heating boiler, should be first discussed.

Several years ago a manufacturer of cast-iron sectional low pressure steam and hot water heating boilers, concluded to never thereafter design or make a heating boiler that would not burn bituminous satisfactorily and in accordance with ordinances, regardless of what fuel it was especially intended for. This manufacturer rates all boilers from tests burning anthracite, it being the only practical fuel to use to obtain uniform outputs under drive, or at rating, or at any percentage thereof for the entire period of fuel available without attention.

The principal advantages sought for in a magazine boiler are:

A reserve fuel capacity, all the way up to twice that of a surface burning boiler of similar rating, insuring a long period between re-coaling.

A less frequent need of cleaning the fire, especially during the medium weather, than obtains with a surface burning boiler.

A more uniform state of combustion flow of volatile gas, theoretically maintaining a uniform mixture of combustible.

A quick pick-up after attention, there being practically no check to combustion or output, as the burning zone is below the bottom of the magazine.

All these advantages are realized at times in a properly designed magazine boiler when burning anthracite, and also at times when burning coke. When burning bituminous, however, the necessity for attention (slicing) becomes more frequent to offset the tendency of the fuel to bridge, especially when outputs approaching full load are required and the fuel is of a strong caking quality; otherwise the per cent of O will become excessive and the per cent of CO_2, the output, and the efficiency will diminish.

Boilers of the magazine, as well as of the surface burning type, when operating at a combustion rate approaching rating, have a tendency to slag portions of the ash into clinker; when this occurs excessively to an extent to check combustion, the clinker is much more readily removed from a surface burning, than from a magazine boiler.

At times it is quite impracticable to slice or stoke large areas of clinker from the burning fuel-bed and remove them from a magazine boiler, and the attempt often so disarranges and thickens the burning fuel bed as to necessitate "dropping the bottom," as it were. When burning sticky grades of bituminous, the selection of either a magazine or a surface burning boiler reasonably larger than the load will lessen the formation of clinker and should help to maintain efficiency and lengthen the periods between stoking.

No. 550

RELATION OF BOILER HEATING SURFACE AREA TO BOILER CAPACITY

By P. J. Dougherty, Utica, N. Y.

Member

In comparing the relative capacities of differently designed heating boilers, it is just as logical for an engineer to compare the relative areas of their fire-doors, or the relative areas of their draft doors or smoke pipes as to compare the relative areas or amounts of heating surface they contain as a means of determining their relative capacities.

Unfortunately, very few engineers, either high or low pressure, appreciate the fact that the standards of high pressure boiler practice, as a rule, have very little application to heating boiler practice. The underlying principles of both agree, although the application of those principles in practice continually diverges.

Scale formation is one of the most important factors affecting high pressure boiler efficiency. Scale formation is a negative factor in low pressure practice. Length of firing period is a most important factor in determining the actual capacity of a heating boiler. Length of firing period is a negative factor in determining a power boiler's capacity. The pressure factor or tensile strength is the most important factor in determining the design of a power boiler, since it is primarily a pressure vessel or apparatus. The pressure factor is practically a negative factor in the design of a heating boiler since it is not a pressure vessel in the general sense of the term.

HEATING SURFACE RULES

In his excellent book on Steam Boiler Economy, Kent states: "For maximum economy with any kind of fuel, a boiler should be proportioned so that at least 1 sq. ft. of heating surface should be given for every 3 lb. of water to be evaporated from and at 212 deg. fahr. per hour." Practically without exception, the leading authorities on heating and ventilation have adopted Kent's rule with slight variations.

Paper presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, January, 1920.

It is also adopted by certain heating boiler manufacturers, as evidenced by the following quotation from a recent catalog of heating boilers: "The size of any heating boiler is the total number of square feet of heating surface which that boiler contains. The.... steam boiler contains 7¼ sq. ft. of heating surface for every 100 ft. of steam radiation." The same make boiler, but of slightly different design, contained, a few years ago, practically double that amount of heating surface per hundred feet of rating as shown later.

The only foundation those authorities and manufacturers have for their heating surface rule consists of false assumptions and far-fetched analogies.

Analyze any rule of thumb such as the above and invariably you will find that its very warp and weave consist of assumption and analogy. A rule based upon such a flimsy foundation is no more stable nor secure than a sky-scraper built upon a stratum of quicksand.

The modern engineer must delve below this quicksand stratum of assumption and analogy till he reaches the bed rock of original research by means of instruments of precision intelligently and accurately applied.

Unfortunately, the engineer in the past, because of a lack of the necessary research data, was compelled to resort to assumption and analogy in formulating his empirical rules as a means of summarizing prevailing practice. This lack of real boiler knowledge, however, is rapidily being remedied by the research bureaus established by the United States Bureau of Mines, our leading universities, boiler manufacturers, and engineering societies such as the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS. It is to be hoped the other engineering societies will follow the latter's example.

KENT'S EQUATIONS OF HEATING SURFACE EFFICIENCY

In his book on Boiler Economy, Kent devotes a chapter of 40 pages to developing a series of 17 very elaborate equations on heating surface efficiency whose superstructure soars up into the higher realms of calculus, while their foundation is based upon the shifting sands of assumption and analogy. The assumptions he makes are legion. We shall consider only the basic ones.

In establishing a basis for those 17 ponderous equations the factor q is introduced which represents the "rate of conduction in Units of Evaporation (*U. E.* = 965.7 *H. U.*) per hour per square foot of heating surface, corresponding to any difference of temperature, $T—t$, of the gas and of the water." Please note how the factor q insidiously correlates the area and temperature factors.

After this factor q is introduced, the next paragraph contains the following false and groundless conclusion, viz.: "since the rate of conduction q decreases in same ratio with the decrease of the difference in temperature $T—t$." There is no such "same ratio" in boiler design, making heating surface area a function of temperature drop or heat conduction.

By means of this false assumption, making heating surface area and heat conduction inter-dependent, the area and temperature factors are first differentiated and then integrated in the formation of equation (2).

Following equation (2) is this statement: "The second member of this last equation may be integrated when we find the law of the relation of q to $T—t$." There being no law in boiler practice that establishes a relation between the rate of heat transmission through a square foot of heating surface and the difference in temperature $T—t$ between the hot gas and the boiler water, it is mathematically impossible to integrate or solve equation (2) upon which the other 15 equations depend.

In his attempt to integrate equation (2), Kent makes the false assumption that Blechynden's experiments established Rankin's assumption as a law, viz., that the rate of heat transfer is proportional to the square of the temperature difference at the two sides of the plate.

Kreisinger, the leading authority on such matters in this country, shows the fallacy of such an assumption when he states:

> Since the rate of heat radiation is proportional to the difference of the fourth powers of the absolute temperatures, and the rate of convection contains the temperature factor as a first power, in the combined rate of heat transfer the temperature factor may appear as the third power or as the square, depending upon whether the radiation or convection predominates. The formula where the square of the temperature difference appears can be applicable only in very special cases.

The fourth power law of radiation stated by Kreisinger was originally deduced by Stefan from experiments and later demonstrated mathematically by Boltzman, from the theory of electromagnetic radiation, to hold good for an ideal black body. The sooted surface of a boiler comes within 4 or 5 per cent of being black, hence this law can be applied to boiler practice without any serious error.

If anything further is necessary to show the worthlessness of the equations in Kent's Heating Surface Efficiency, the following will suffice from Technical Paper No. 114, Bureau of Mines:

> No single equation based on temperature alone can be made to express the rate of heat transmission from the hot gases into the boiler water. The equation given in some text books, which states that the rate of heat transmission is proportional to the square of the temperature difference between

the hot gases and the boiler water, is only roughly approximate and is practically worthless for steam boiler problems.

KENT'S HEATING SURFACE RULE OF 1 TO 3

Having disposed of the equations we shall now proceed to do likewise with the 1 to 3 rule and thus show the fallacy of the many varieties of this rule contained in the leading books and articles on heating and ventilating and in a few boiler catalogs.

The efficiency or amount of steam developed through heating surface does not depend upon its area or amount but primarily upon the design or arrangement of the heating surface which is influenced by numerous other factors and laws. Bulletin No. 18, Bureau of Mines, states:

> It should be stated in connection with the locomotive furnace that when the temperatures remain constant the amount of heat received by the boiler by radiation depends on the area or extent of the fuel bed (when the top of the fuel bed is approximately a plane surface) and not on the exposed area of the boiler's heating surface. That is, referring to Fig. 49 (see Fig. 1), the amount of heat radiated to the boiler would be the same if the inside of the firebox had the shape shown by the dotted line B'.

Hence the amount of steam generated by the radiant heat through the walls of the fire box of an internally fired boiler, depends upon the temperature and area of the fuel bed and not upon the area of the heating surface contained in the walls of the firebox.

This statement is a knockout blow to the arguments of most boiler salesmen, and numerous heating boiler catalogs, that a properly designed boiler should contain two-thirds direct and one-third indirect heating surface.

Continuing, Bulletin 18 states:

> At the same temperatures the net quantity of heat exchanged between the hot fuel surface and the boiler surfaces depends upon the extent of the hot surface and the angle of exposure of the hot surface to the boiler surface. Figure 52 (see Fig. 2) further illustrates this feature. Let *A* be a small unit of the hot fuel surface and *ABC* be the cold heating surface. Now, the cold surface does not receive any more heat from the small area *A* of the hot surface, even though the former has the shape *AB'C* or *AB"C*; although in the latter two cases the cold surface may have twice as much area as in the first case. Again, if the cold surface *DEF*, having four times the area of *ABC*, be placed at twice the distance from *A*, the quantity of heat received from *A* will be the same as was received by the cold surface *ABC*. Neither would the quantity of heat be increased if corrugated cold surface *DE'F* or *DE"F* were substituted for *DEF*. From this illustration, it will be noticed that the radiant heat resembles light in every respect, a resemblance that is confirmed by physicists.

The above fact explains why the later designed boilers have no corrugated crown sheets or overhanging water legs projecting into the combustion space over the fuel bed.

According to this same Bulletin No. 18:

If the same weights of gas at the same initial temperature are passed through a 2 in. and a 4 in. flue, both flues having the same length, the 2 in. flue will absorb more heat than the 4 in. flue, although the 4 in. flue has twice as much heating surface as the 2 in. flue.

The test chart shows that although the large flues of boiler No. 2 have more heating surface than the small flues of boiler No. 1, the air comes cooler from the small flues than from the larger ones. This is an important feature which brings out the fact that it is not the area but arrangement that makes heating surfaces efficient.

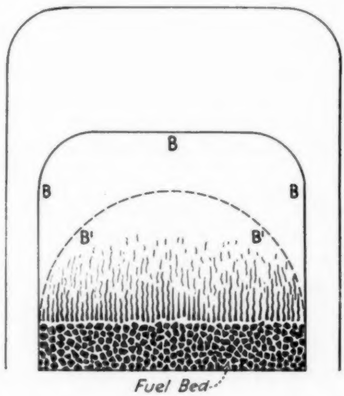

FIG. 1. DIAGRAM SHOWING EXTENT OF FUEL BED.

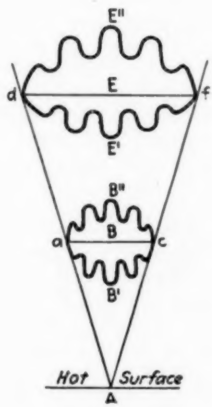

FIG. 2. DIAGRAM SHOWING ANGLE OF EXPOSURE OF HEATING SURFACE.

There is just as much logic in saying that the heating surface necessary to produce one boiler horse power is 20 or 3 sq. ft. as in saying that it is 10 sq. ft.

The dogmas that the area of grate should have a certain ratio to the area of the heating surface, and that it takes 10 sq. ft. of heating surface to make one boiler horse power, seemingly have become so thoroughly fixed in the mind that they are hardly ever questioned. It is only within the last decade that a few engineers have broken away from the old rule of thumb methods and have begun to investigate the function of the boiler and furnace separately. Their studies seem to mark the beginning of advance in steam generating apparatus.

Considering that those statements are made by the highest authority on such matters after a thorough investigation and long series of tests, it is to be hoped that the leading authorities on heating and ventilating will keep abreast of the times by revising their

discredited rules of comparing boiler capacities on a grate area and heating surface area basis and adopt the only real boiler capacity rule as formulated by the Committee of the Society on Code for Testing Low Pressure Heating Boilers.

HEATING SURFACE CAPACITY

The evaporative tests conducted by Wood and Dewrance demonstrated that the location or design of the heating surface primarily determined its steam generating capacity, while its area or amount depended upon other features of the boiler design. Their experiments on a boiler of the locomotive type showed "that the first 6 inches of the tubes did more work than the next 60 inches."

Tests, conducted on locomotives by engineers of the Northern Railway of France, as reported by Havrez, confirm the findings of Wood and Dewrance, according to which "from 2/5 to ½ of the whole quantity of water was evaporated from the surface of the firebox section, although this surface was less than one-tenth of the whole heating surface."

According to those tests, about 70 per cent of the steam generated by boilers of the locomotive type is produced by the heating surface of the firebox and the first 6 in. of the tubes, containing less than 20 per cent of the total heating surface. The remaining 80 per cent of the heating surface of such boilers produce only about 30 per cent of the steam and hence are of relatively low efficiency.

In commenting on the evaporative tests made by Hirsch, in his book on Steam Boilers, Rowan states that those "experiments give proof that an evaporation of from 50 to nearly 100 lb. of water per hr. per sq. ft. of heating surface may be obtained without seriously heating the metal of the boilers, when these are properly constructed and the surfaces are clean."

Rowan's statement of the high capacity of properly designed heating surface is confirmed by tests conducted by the U. S. Bureau of Mines as set forth in Bulletin 135: "Each sq. ft. of heating surface transmitted an amount of heat equivalent to 4.6 boiler horse power, or one horse power was generated on less than 0.22 sq. ft. of heating surface. These figures compare favorably with the figure 0.357 sq. ft. of heating surface per boiler horse power which is the rate of heat transmission of the lower row of boiler tubes at the point where the hot products of combustion first come in contact with the boiler as determined in tests described in Technical Paper 114." This is equivalent to 96 lb. of water evaporated per sq. ft. of heating surface as compared with Kent's average of only 3 lb. per sq. ft. of surface.

Since a square foot of heating surface properly arranged can practically generate 100 lb. of steam per hr., it is evident that the

average efficiency of a square foot of surface in power boilers is exceedingly low at only 3 lb. of steam per hour.

The same can be said of most heating boilers. Those that have been recently designed, however, show a marked improvement of nearly 300 per cent by giving an average evaporation of 8 lb. of water per sq. ft. of heating surface with an overall efficiency of over 9 lb. of water evaporated from and at 212 deg. fahr. per lb. of standard hard coal, when developing their rated capacity.

The amount or area of heating surface in a heating boiler designed along modern lines is of such minor importance that the engineer who designs it does not, as a rule, know it himself until the boiler has been tested and rated and placed on the market, after which some wise architect or heating contractor insists upon knowing it. The engineer who designed the boiler is then compelled to figure it up for the first time. The arrangement or design of the heating surface is what the modern designing engineer worries about but he doesn't give a thought to the area or extent.

HEATING SURFACE IN HEATING BOILERS

The Testing Code Committee of the Society in its report very wisely put the quietus on the "generally accepted theory of boiler tests that all relations of one part of a boiler to another should be taken into account, that is, ratio of heating surface to grate surface, proportion of direct surface to indirect, etc."

A study of the chart shown in Fig. 3 will clearly justify the stand taken by the Committee in condemning the old heating surface rule as a factor in determining the capacity of a heating boiler. This chart shows the amount of heating surface in boilers made by five of the leading heating boiler manufacturers of the country, three of whom make sectional cast-iron boilers, one, steel firebox boilers, and the others, steel magazine boilers, thus including the various types and makes of heating boilers.

Please note the various amounts of heating surface five of the leading manufacturers place in their boilers rated at 2000 sq. ft., ranging from 70 sq. ft. to 315 sq. ft., a variation of 450 per cent.

The heating surface in the boilers averaging 3000 sq. ft. capacity ranges from 100 sq. ft. to 380 sq. ft., etc.

If, as previously quoted from a boiler catalog, "The size of any heating boiler is the total number of sq. ft. of heating surface which that boiler contains", how does this manufacturer account for the fact that his 2000 sq. ft. boiler in 1913 contained over 300 sq. ft. of heating surface, while in 1917 his 2000 sq. ft. boiler contains only 145 sq. ft., a difference of over 200 per cent? Standards shouldn't be so elastic.

The five different signs represent the different manufacturers, although from one to three different types or designs of boilers by the same manufacturer are included and represented by one sign.

Note if you will that the maker represented by a dot (.) makes two 8000 ft. boilers, one having 600 sq. ft. of heating surface and the other only 429 sq. ft. Another maker places less heating surface in his 9375 ft. boiler than in his 4800 ft. boiler, which is of different design.

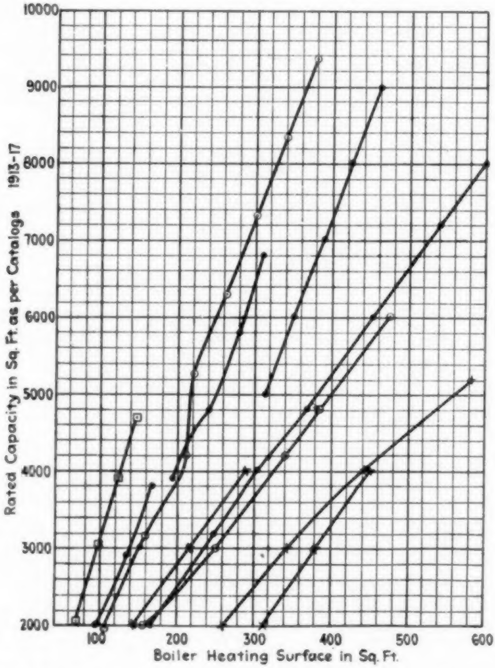

FIG. 3. DIAGRAM SHOWING RELATIONS OF HEATING SURFACE TO RATING OF BOILERS OF FIVE WELL-KNOWN MANUFACTURERS.

Isn't it self-evident from this chart that the engineers and manufacturers, who design and make boilers, entirely ignore Kent and his satellites in the heating line and all their fine-spun theories regarding the value of heating surface area as regards boiler capacity? Here is one case at least where the manufacturers are right and the engineers with their discredited rules of thumb on heating surface value were all wrong.

Since old ideas and notions die hard, some may say the grate area and heating surface area should be considered together. The grate area varies just as much as regards boiler capacity as the heating

surface area. To save space merely a few examples from the above manufacturers of cast-iron boilers will be given, represented by letters A, B and C, in Table 1.

If grate area is such an important factor to consider in determining boiler capacity, why is it that two boilers made by the same company are rated at 8,000 sq. ft. and 4,650 sq. ft. and still have the same size grate of 18 sq. ft.? Also another concern has a larger grate in its 4,200 sq. ft. boiler than in its 5,400 sq. ft. boiler. These discrepancies apply to all boilers of different design.

TABLE I. COMPARISON OF RELATIONS OF GRATE AREA TO RATED CAPACITY IN DIFFERENT BOILERS

Maker	Grate Area, sq. ft.	Rated Capacity, sq. ft.
B	15.96	3,675
B	16.00	4,800
A	16.00	7,200
C	16.61	4,700
A	18.00	4,650
B	18.00	5,275
B	18.00	5,400
A	18.00	8,000
B	18.24	4,200

A progressive engineer never hesitates to throw his theories overboard when they conflict with cold-blooded facts. Theories come and go, but facts remain forever.

A REAL BOILER CAPACITY RULE

In its heating boiler capacity rule the American Society of Heating and Ventilating Engineers has established a standard that will stand the test of time, because like the house in Holy Writ, it is founded on the rock of truth and justice.

The rule is quite simple and practical and contains but three factors. To determine a boiler's capacity in pounds of steam per hour, you multiply the available fuel capacity in pounds by the evaporative power in pounds and divide by the length of firing period in hours.

The evaporative power is the number of pounds of steam from and at 212 deg. fahr. the boiler can generate from a pound of standard grade of fuel. With hard coal the available fuel shall not exceed 80 per cent of the boiler's fuel capacity.

Those factors must be determined by actual tests in accord with the rules of the Boiler Test Code.

The Testing Code Boiler Capacity Rule entirely ignores both the grate area and the heating surface area as factors in determining a

boiler's capacity, because it is the design of the boiler and not the amount of heating surface or grate it contains that determines its capacity.

DISCUSSION

A. A. CARY: I note that Mr. Dougherty takes exception to Professor Kent's formulae used in calculating efficiency of heating surface, and am sorry to find that he has not found their true value, as I have. Possibly, had he used them in making extended boiler investigations and in applying them to boiler design, as I have had occasion to do, he would have a better appreciation of their value.

Mr. Kent specifically states in his book on "Steam Boiler Economy" that with the lower temperatures, such as are found in house heating boilers, where but small differences of temperature are found, the transmission of heat through the metal plates is nearly *proportional* to the difference of temperature on the opposite sides of the heating surface, but in cases where high pressure boilers are used, with their higher furnace temperatures and much greater difference of temperature of the fluids on the two sides of the plate are found the transmission increases at a faster rate than the simple difference in temperature so that it is nearly proportional to the square of the difference in temperature.

Many carefully conducted experiments have satisfied me that this statement is correct and I have made extended use of it in high pressure boiler design with most satisfactory results.

Food for thought in this connection may be gathered by examining a number of high pressure boiler tests, where boilers are operated first with low furnace temperatures and then operated with high furnace temperatures and where the boilers contain an ample amount of heating surface.

Notwithstanding a large increase in furnace temperature, it will be found that the temperature of the escaping gas, which has passed over the same area of heating surface, is not raised to any such degree proportionate to the temperature increase in the furnace. This is due to the greatly increased rate of heat transmission with the higher temperature furnace gases.

The historic tests of the experimental locomotive boiler in France, as reported by Havrez and referred to in Mr. Dougherty's paper, show most conclusively that, aside from the evaporation in the fire box portion of this boiler, the transmission of heat varied as the square of the difference in temperature between the two sides of the heating surface of this boiler.

In these Havrez tests, the locomotive boiler used was divided into a series of separate compartments so that the evaporation in the

individual cross divisions of this boiler could be separately determined.

The first compartment included that portion of the water containing interior entirely surrounding the fire box, then followed a succession of water containing chambers between the fire box and the stack, from which the furnace gases escaped.

The steam generated in each successive compartment was carried to condensers from which the resulting water was weighed and thus the evaporative value of each part of the boiler was carefully determined.

The greatest rate of heat transmission was obtained in the compartment surrounding the fire box and Mr. Kent, in his "Steam Boiler Economy" calls attention to the fact that a higher rate of heat transmission occurs where the heating surface receives the heat directly radiated from the fire bed than when the heat is carried to the boiler surface by the flowing furnace gases.

Mr. Dougherty has referred to Mr. Kreisinger's statements given in the Bulletin of the Bureau of Mines, regarding rate of heat transmission in boilers. Possibly, if Mr. Dougherty had followed the considerable adverse criticism to these statements, he would not have used this quotation as he has.

I am sorry to find that Mr. Dougherty is inclined to scrap the very valuable information that has been developed concerning the transfer of heat in boilers and substitute the old time rule of thumb methods used previous to the date when our Society was formed. That procedure is hardly in line with the purposes which led the Heating and Ventilating Engineers to organize.

J. R. ALLEN: I approve of the general idea of Mr Dougherty's paper. I do not think one can compare standards for power boilers and the principles and design of power boilers with those of house-heating boilers. They are different types of apparatus. I have often characterized them in this way: the power boiler is dynamic and the house-heating boiler is static. In the power boiler the drafts are open practically all the time; there is a uniform or almost uniform rate of combustion and the gas passes through the boiler at all times at a fairly high velocity. In the house-heating boiler, on the other hand, it is only during the period of firing, when the drafts are pretty well open, that gases pass with any degree of rapidity through the boiler and flues; after a very short period of firing, the drafts are almost closed and the boiler is in a static condition.

In a static condition, the fire surface of the boiler is doing practically all of the work. When the fire surface is doing the work, it does it by reduction of temperature in the fire bed; during this period the fire surface of the boiler is completely effective. I discovered this early in my experience with heating. I put in an ordinary vertical type of fire tube boiler to heat a house and of all the unsatis-

factory boilers I ever put in a house, that one was the most unsatisfactory. The boiler had no fire surface to receive the radiant heat of the fire during periods when the draft was closed.

A house-heating boiler does not require as much flue surface as a power boiler. On the other hand, a boiler can be put in with so little flue surface that the moment there is anything like good combustion at average load, there will be a very high temperature at the stack and therefore great loss of heat. There must be, therefore, a reasonable proportion between fire and flue surface. In a house-heating boiler, there should be a much larger proportion of the fire heating surface than would be necessary in a power boiler. To apply power boiler rules to the house-heating boiler would be entirely out of the question. A house-heating boiler cannot be rated in the same way as a power boiler. The rating of a house-heating boiler should be from a curve of performance, and that is exactly what Mr. Dougherty and the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS' rules recommended. With a curve of performance a boiler can be selected that will be suitable for its load and conditions of operation and this is the only proper basis for selecting a house-heating boiler. We have the curve of performance of fans, the curve of performance of electrical machinery, a curve of performance of hydraulic machinery; let us have the same thing for house-heating boilers.

C. F. NEWPORT: Since Mr. Dougherty has quoted several bulletins in his article, in reference to one of which he says, "If anything further is necessary to show the worthlessness of the equations in Kent's heating surface efficiency, the following will suffice from Technical Paper No. 114, Bureau of Mines." In other words, he accepts the quotation from that bulletin in preference to Kent's formula.

In another place he says, after quoting from another bulletin, "considering that those statements are made by the highest authority on such matters after a thorough investigation and long series of tests."

E. H. LOCKWOOD (written): Mr. Dougherty's paper points out the inconsistencies of manufacturers in rating low-pressure boilers on heating surface or on grate surface, and suggests logically the need of a rule for capacity rating which shall escape these defects. It is true that no capacity rating has been adopted yet by manufacturers of low pressure boilers, and it is quite possible that, as in the case of steam engines, no capacity rating will ever be agreed upon.

It may be helpful to examine briefly two capacity rules that have found wide acceptance. Power boilers are rated on their heating surface only. Gasoline engines are rated on the bore of the cylinder only. Both rules are admittedly defective, since the capacity is based on one element only, while others are not taken into account. In many installations, the capacity developed by test is greatly in excess

of the rated capacity by the rule, yet in the report of the test both rated capacity and actual capacity are mentioned and compared. The reason for the general adoption of these rules is presumably, that they give a fairly approximate value for the output of boilers and gasoline engines under average full load conditions. Furthermore the rules are perfectly definite and easy to apply.

A capacity rule has been proposed in the Code for Testing Low Pressure Boilers adopted by this Society. Unlike Mr. Dougherty, I am unable to give this rule the endorsement of being "simple and practical," perhaps because it differs so radically from other capacity rules. As I interpret the rule, it says, in substance, the rated capacity is equal to the boiler capacity as found by test. Accordingly the rated capacity is not a fixed quantity, but a variable quantity depending on the firing period and the kind of fuel. The rated capacity would be stated, not as a single number, but as a table with columns and rows applicable to different firing periods and fuels. To make sure that my interpretation is correct, the rule is repeated here, using Mr. Dougherty's words:

"The rule is quite simple and practical and contains but three factors. To determine a boiler's capacity in pounds of steam per hour, you multiply the available fuel capacity in pounds by the evaporative power in pounds and divide by the length of firing period in hours.

These factors must be determined by actual tests in accord with the rules of the Boiler Test Code."

It is clear to me that this *rule* is in effect not a rule, but a statement of boiler capacity when operating under any test conditions that the experimenter decides to adopt. Its working may be represented by a hypothetical case. Two different experimenters make a test of the same boiler, one using an eight hour firing period and the other a four hour period. One observer reports a capacity of 600 lb. equivalent evaporation per hour, while the other reports a capacity of 1200 lb per hour. They talk it over and decide that boiler capacity means anything, depending on how the boiler is run.

Personally I should favor a capacity rule based on the boiler dimensions only. Fully realizing the difficulty of formulating any rule I beg to suggest one that has the merit of utmost simplicity, at least. The capacity of a boiler is determined, primarily, by the rate at which coal is burned, and this is determined by the draft, the kind of coal and the size of the grate. For ordinary draft and for the same kind of coal, the capacity depends almost wholly on the grate area. Eight pounds of coal per hour can be burned on a square foot of grate with average draft and average quality. Each pound of coal will evaporate 9.5 lb. of water (equivalent evaporation), making 76 lb. of steam per hour, equal to 300 ft. of steam radiation, for each square foot of grate area. Hence the following rule:

Rated Capacity (steam radiation) = 300 x grate area in sq. ft.

This rule is intended for steam boilers only, having flat grates. It would not be suitable for magazine boilers or for double-grate down-draft boilers. The capacity given by this rule is probably about the maximum for the average boiler with a short firing period. For longer firing periods the capacity would be less than that given by the rule, and its value should be given by the manufacturers' tables of tests.

It is proper for the Low-Pressure Boiler Code to omit a rule for capacity rating, or even to state that no such rule exists. It is puzzling to be told that the Code contains a "real capacity rule" when as a matter of fact the code contains no rule, but simply the statement that the capacity of a boiler is whatever it shows by test, which may range from nothing to a maximum, depending on the size of the boiler.

THE AUTHOR: Regarding Mr. Newport's criticism, I wish to inform Mr. Newport that Mr. Kent wrote this book on power boilers. However, I quoted from Kreisinger on Power Practice, so I was consistent. The quotations I took from Kreisinger apply to power boilers. All my quotations are from Kreisinger, who is the head of the Coal Research Bureau in Pittsburgh—a very prominent and capable man, one of our great research physicists.

Answering Mr. Cary, the old engineers never separated the two factors, radiant heat and convected heat. That is where the square comes in. There are two factors there, combining in one. The radiant heat varies with the fourth power and convected heat with the first power only. It may be possible to join the first and the fourth to obtain a square, but that is a haphazard combination and not based on sound engineering.

No. 551

OIL AS A FUEL FOR BOILERS AND FURNACES

By H. H. Fleming[1], New York, N. Y.

Non-Member

FOR several decades, some of our Southern states and the entire Pacific Coast have enjoyed the use of fuel oil but until very recently it has not been used along the Atlantic seaboard except to a limited extent for marine boilers and industrial furnace work. As a result there are few people in this part of the country, even among engineers, who are familiar with it. In the last few months, however, fuel oil has become available in large quantities and at a lower price than coal throughout the Atlantic coast region. Those engineers who know the many advantages of this excellent fuel have been quick to profit by its availability and from Canada to the Gulf of Mexico plants are being equipped to burn oil under their boilers. This is particularly true of the larger plants, which employ high grade combustion engineers who have made a careful study of all fuels and are ever alert to take advantage of changing conditions. But the small consumer, spurred on by the rising cost of coal and the labor incident to the handling of coal and ashes, is also awakening to the possibilities of oil as a clean, cheap fuel, with the result that many office buildings, hotels, apartments and even private dwellings are now burning fuel oil.

NATURE OF FUEL OIL

Crude oil can be used as fuel but most of the oil marketed today for fuel purposes is refined. The light, volatile fractions are removed from the crude, and made into gasoline, kerosene, gas oil, etc., leaving the heavier fractions in the fuel oil. This "topping," as the process is called by refiners, not only conserves the more valuable oils for the automobile, aeroplane, tractor, and many other urgent demands, but produces a better and safer oil for fuel purposes. The light fractions having been removed, the residual fuel oil will not give off inflammable vapors until heated well above atmospheric temperatures and is therefore much safer to handle

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and store. Certain of the Mexican wells notably those in the Panuco district, produce a crude of low gravity (about 12 deg. baume), and containing only a very small per cent of volatile oils. These light fractions are soon lost in storage and transportation so that the crude is not worth topping today. This Panuco crude makes a very good fuel oil if, in the storage and handling of it, proper precautions are taken. It differs from the standard topped Mexican oil in that it is slightly heavier and has a lower flash point (the temperature at which it will emit inflammable vapors). 150 deg. fahr., or higher with the closed cup tester is the usual flash point specified for marine work.

AVAILABILITY

Fuel oils may be made from any crude but the heavy fractions of low-sulphur, paraffin base crudes are too valuable for lubricating stock, paraffin wax, and other products to be burned as fuel for boilers. However, the asphaltum base crudes that are now so plentiful can be used for little else than fuel oil and asphaltic road binders after their small percentage of light oils has been removed. Consequently, refineries running such crudes are compelled to dispose of great quantities of fuel oil in order to secure the gasoline and kerosene from the crude. The oil companies must market this fuel oil in competition with coal for there is no market of sufficient breadth to absorb such large quantities of fuel except in the field where coal has been used in the past, so that as long as there is a demand for gasoline and kerosene, fuel oil will be sold at a price to compete with coal. Of course the supply may be limited to those plants whose locations permit cheap transportation from the refinery.

These cheap crudes consisting largely of fuel oil have not been available until very recently as they come mainly from Mexico. The Mexican production did not reach large proportions until shortly before the war started. During the war the government had control of the tank steamers which were taken from the Mexican-United States traffic for trans-Atlantic work to supply the crying needs of the Allies for petroleum products of all kinds. The result was a scarcity of fuel oil for shore work and no plants were allowed to use oil if they could operate on coal.

Many tankers were sunk by submarines during the war, but our shipbuilding program included a large number of oil carriers so that those lost were quickly replaced and many more are now being built. The war situation having cleared up during the past few months, transportation from Mexico is now nearly normal again and millions of barrels of crude are sent every month to this country where it is topped by large refineries scattered along our Gulf and Atlantic coasts.

Mexico exported 35,000,000 bbl. of oil in the first six months of 1919 and the total for the year is expected to exceed 80,000,000 bbl. But even this vast quantity, which is about five times as great as

that produced in 1912, is only a small part of the potential production of Mexico. In 1918, 63,826,000 bbl. were actually produced and yet this was only 11 per cent of the estimated potential production. There are single wells in these fields capable of producing over 100,000 bbl. daily. Many wells have been capped or their production greatly cut down awaiting transportation facilities, i.e. pipe lines to the coast and tankers to receive it there, both of which are being constructed as rapidly as possible. Practically the entire Mexican production comes from a strip of land running along the coast for a little over 100 mi. and averaging about 50 mi. wide, the principal port of which is Tampico, at the mouth of the Panuco River. This city is the center of the Mexican oil industry. With the navies and merchant marines of nearly every country on the globe depending upon oil for their motor power, it seems safe to assume that the Tampico fields will always be available to the entire world regardless of the course of Mexican politics. Mr. Ed. N. Hurley as Chairman of the United States Shipping Board made an exhaustive study of the petroleum situation and the advantages of oil as a boiler fuel with the result that practically all of the boats being built by the Shipping Board are oil burners and many former coal burners are now being converted. In a very interesting paper on the subject Mr. Hurley writes as follows:

> "Within the next generation and perhaps the next decade, the world seems certain to enter a new era—the petroleum age. Oil will be widely used for industrial power and heating all over the globe. Already there is a marked diversion to oil fuel in industrial centers along the Atlantic seaboard.
>
> It is estimated, roughly, that one man can produce 300 tons of coal yearly, while the same man might produce 7,000 tons of oil. This great multiplication of human power is a benefit that will irresistibly make its own way, and, besides greater results for men's work, there are the additional advantages of clean industrial towns, more agreeable working conditions, better morale, and better living all round.
>
> It is so very much worth while to bring the world into this petroleum age that development of new oil resources all over the globe will be one of the chief activities of peace. The world needs Mexico's petroleum for its growth and comfort. Under the earth in the Tampico district are resources capable of influencing the history of the world.
>
> Out of the lessons of international adjustment and teamwork taught the nations by war they will unquestionably find methods of making the Mexican oil supply available to mankind—methods which will not only be entirely fair to the Mexican people but which will bring them stability, growth, and prosperity."

THE ADVANTAGES OF FUEL OIL OVER COAL

When a plant is converted to fuel oil the big problems of the operator are eliminated; labor troubles, ash disposal, coal handling, fire in the coal pile, smoke nuisance, varying quality of fuel, inability to meet peak loads, insufficient draft, coal frozen in the cars, high standby losses—in short, those things that make life miserable for the man in charge of the plant and high costs for the man who pays for the steam.

The labor saved depends largely upon the size of the plant. Of course if there is only one man in the boiler room there will be no saving in wages but that one man will have very little to do and can often take care of other work at the same time. Where 100 men are employed in a hand fired boiler installation probably 10 to 20 would replace them when burning oil. One man can easily attend to the firing of 8 to 12 boilers.

It is becoming continually more difficult to secure fire-room labor and industrial conditions are such that often only the lowest type of labor can be obtained for such work. The man who regulates the oil burners does not need to possess the physical strength neces-

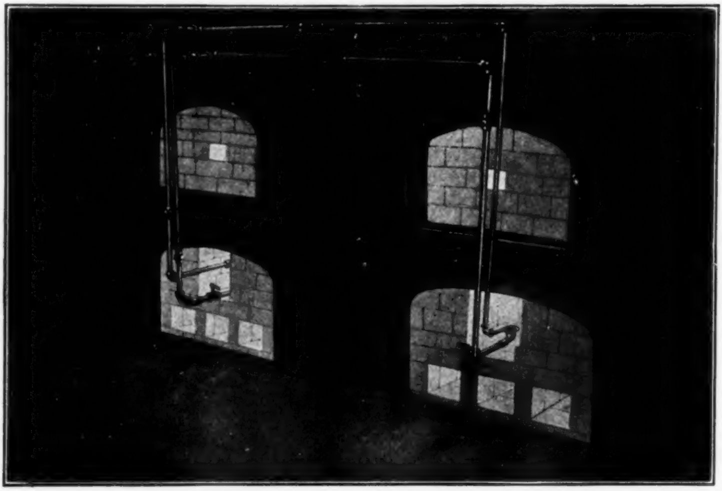

FIG. 1. TYPICAL APPLICATION OF OIL BURNERS TO THE FURNACE OF A HORIZONTAL RETURN TUBULAR BOILER.

sary to wield the shovel and slice bar all day, nor does he require the skill, experience and intelligence necessary to operate stokers at high efficiencies. It is an entirely different class of men that we have to choose from when employing boiler operators for an oil-fired plant and aside from the fireman there is very little labor necessary as the handling is merely a matter of pipe lines and pumps and there are no ashes.

The oil-fired boiler room is clean and cool, there is neither dust, nor clinkers and no work to be done but the regulating of valves. Under such conditions the labor question is easily settled.

The efficiency obtained, on tests of boilers burning oil, range from 75 to 85 per cent. Plant efficiencies over a long period of time run about 80 per cent or something over 15 lb. evaporation per lb of

oil. The latter figure is based on 18,500 B. t. u. per lb. or approximately 150,000 B.t.u. per gallon for 14 baume fuel oil.

Mr. C. R. Weymouth in a paper[1] given before *The American Society of Mechanical Engineers* shows an average net efficiency of 83 per cent over a period of two and one-half years.

The plant efficiency can be kept very much closer to test efficiency than in a coal-fired plant. It requires no more effort on the part of the operator to burn oil economically than it does to waste it and a foreman walking through the plant can tell by a glance at the furnace whether the burners are properly regulated or not, even though he has no elaborate instruments for checking the fireman.

If any furnace shows signs of poor combustion it is only a matter of seconds and the turning of a valve before the fire is right again. In a coal fired plant it takes a good man to find the wasteful fires and then considerable time and effort is spent before they are improved.

In plants whose load varies to any extent, coal is at a great disadvantage as compared with oil, for with the latter, standby losses are reduced to a minimum. For instance, in New England mills operating one 8 or 10 hr. shift, their engineers estimate that 20 to 25 per cent of the total coal consumed is used for banking fires. With an oil-fired boiler it is necessary only to shut off the oil supply and close the air inlets. The heat from the hot brick work is then sufficient to maintain practically full pressure for several hours. If a light load is to be carried during this period one burner can be kept going but turned low.

When peak loads are encountered oil has much the same advantage as in carrying light loads or, in other words, the load efficiency curve is very flat as compared with that for coal. No matter how sharp the peak demanded, the oil-fired boiler quickly supplies it with little or no drop in pressure and with no more effort on the part of the boiler room crew than if the load had slackened.

There is no cleaning of fires with the accompanying lack of steam and unpreparedness to meet sudden demands. With no fires to clean and no doors opened to admit a rush of cold air with each shovelful of coal, the loss of unburned fuel through the grate is entirely eliminated and the stack loss greatly reduced. There is usually less than 25 per cent excess air going through the furnace and the heating surfaces are relatively free from soot and dirt. With these factors in mind, it is easy to see how plant efficiencies of over 80 per cent are maintained.

To many fuel users the cleanliness and convenience of oil means as much as the economy or labor saving. The elimination of smoke and cinders appeals to the owner as well as to the surrounding community. Through some of our forest preserves, the railroads are required by law to burn oil in order to prevent forest fires.

[1] Published in Journal of The American Society of Mechanical Engineers, June, 1919.

A perfectly clear stack is not desirable because it usually indicates an excess of air. A slight almost imperceptible haze is the best indication of good combustion, for it assures us that no more air is being admitted than necessary to burn the oil and yet very little fuel escapes unconsumed. After seeing pictures of smoke screens emitted by oil burning destroyers many have the impression that dense black smoke is inherent to oil burners. As a matter of fact, one of the greatest advantages of oil to naval vessels is the fact that with their normally clear stacks they are invisible when below the horizon.

FIG. 2. INTERIOR VIEW OF FURNACE OF HORIZONTAL RETURN TUBULAR BOILER ARRANGED FOR BURNING OIL FUEL.

EQUIPMENT

The equipment required for a fuel oil installation consists essentially of storage tank, pump, heater and burners with the interconnecting piping. A simple duplex pump is usually used to deliver the oil to the burner and between the pump and burner a heater is installed which raises the oil to a temperature close to its flash point. The function of the burner is to atomize the oil and spray it into the fire box where it is burned in suspension. The atomizing is done by steam, air, or pressure with hundreds of different types of burners using each method. It seems as though every man who ever burned oil designed an oil burner of his own and patented it. Each designer makes broad claims for his burner but I think it was Kent who said that, as long as a burner atomized the oil, its design should have no more effect on the boiler efficiency than the

design of a coal shovel would have with a coal fired boiler. The important qualifications of a good oil burner are, (1) that it shall atomize the oil to as near a gaseous state as possible, (2) that it shall operate with a minimum consumption of steam or other atomizing medium, (3) that it shall not clog or suffer from the eroding effects of the steam and oil.

Mechanical burners atomize by forcing the oil under 100 to 300 lb. pressure through slots so arranged that the oil is given a whirling motion. This type of burner is used exclusively in marine work because no water is lost up the stack in the form of atomizing steam; what steam is used by pumps and heaters is condensed and returned to the boiler.

Burners which atomize by compressed air have been used on board ship but the compressor equipment is expensive, bulky, and costly to maintain. The same objections apply to air atomizing in shore plants but it is used in many installations when steam is not available or not desirable for the particular work done. Air gives a short intense flame and is better than steam for some metallurgical work.

For the great majority of stationary plants and locomotives steam is the atomizing medium used, principally because it makes the simplest installation. The amount of steam required for atomizing varies somewhat with different burners. A good burner properly operated will consume 2 to 3 per cent of the total steam generated or roughly 3 to 4 lb. of steam per gal. of oil.

The furnace design, not the type of burner, is the important part of the installation. The proper furnace arrangement for burning oil does not differ materially from one designed for burning coal so the change from one to the other is generally simple and inexpensive. However, there are several points that have to be kept in mind in making such a change, the most important of which is that the flame from the oil burner must not be allowed to impinge directly on any heating surface. The firebox must be large enough to permit complete combustion before the flame is cooled by contact with a boiler surface in order to prevent incomplete combustion and the burning out of tubes. A hand fired boiler is often converted to oil by merely covering the grate bars with fire brick, laid loosely, leaving a suitable air space directly under and in front of the burner which is inserted in the fire door. To secure a larger combustion chamber, the grate may be taken out and the burner placed in the ashpit. A floor for the ashpit should then be built of loosely laid brick so supported as to admit air underneath them. The hot brick will then preheat the incoming air. Some prefer to fire from the bridgewall and every engineer has his own theories as to the value of checkerwork, arches, etc.

Fig. 1 shows the front of a typical oil fired boiler. Fig. 2 illustrates one method of firing a horizontal return tubular.

The stack required for oil is smaller than that used with coal to obtain the same capacities because less excess air is used and it is shorter because only sufficient draft to force the gases through the boiler and breeching is needed, there being, of course, no fire bed. Forced draft equipment is discarded except with mechanical burners, where it is possible to use it if exceedingly high ratings are required.

TABLE 1. RELATIVE VALUE OF COAL AND OIL

Gross Boiler Efficiency with Fuel Oil *	Net Evaporation from and at 212° F. per pound of oil	Water Evaporated from and at 212° fahr. per lb. of coal				
		6	7	8	9	10
		Barrels of Oil Equal to One Ton of Coal				
75	13.92	2.565	2.993	3.420	3.848	4.275
76	14.11	2.532	2.954	3.376	3.978	4.220
77	14.30	2.498	2.914	3.330	3.746	4.162
78	14.49	2.465	2.876	3.286	3.697	4.108
79	14.68	2.433	2.838	3.243	3.649	4.054
80	14.87	2.402	2.802	3.202	3.602	4.003
81	15.06	2.371	2.767	3.162	3.557	3.952
82	15.25	2.342	2.732	3.122	3.513	3.903
83	15.44	2.313	2.699	3.085	3.470	3.856
84	15.63	2.285	2.667	3.049	3.431	3.813
85	15.82	2.257	2.635	3.013	3.391	3.769

The above table is based on a constant calorific value for oil and coal. This table is not an accurate basis for comparison, but is useful only as a rough guide for the relative values of the two fuels. The only method of accurately estimating the value of the two fuels is to consider the operating expenses of the plant with each in turn, including the costs of all items entering into the problem. Some of the features to be considered in comparing the two fuels are the space available for fuel storage, the labor saving possible, the hours which the plant is in operation, the load factor, quantity of coal for banking fires, etc.

* Gross Boiler Efficiency includes steam generated which is used for burning oil. Gross Efficiency = Net Efficiency + % used in atomizing oil. One barrel of oil weighs 336 lb. One barrel of oil contains 42 gallons.

TRANSPORTATION AND STORAGE

The oil is loaded from storage tanks at the refinery into barges, tank cars, or tank trucks, for delivery to the consumer. The barges used vary in capacity from 2,000 to 20,000 bbl. (42 gal.) and are equipped with pumps for discharging the oil. Tank cars are built with capacities of 6,000 to 12,000 gal., the most common size being 10,000 gal. For handling the heavy oil these cars are equipped with steam coils so that they may be readily unloaded in cold weather. Tanks of from 1,000 to 2,000 gal. capacity are mounted on automobile trucks for delivery to consumers who can not receive tank car or barge deliveries.

The storage tanks are of steel or concrete and may be above ground or below, depending upon their size and the local conditions. Tanks are provided with steam or hot water coils as the heavy oil should be about 100 deg. fahr. to pump easily. These coils are usually supplied by the exhaust from the pump, not much heat being required since the specific heat of the oil is approximately 0.5.

The relative values of steel and concrete tanks have been discussed at great length, but which is the cheaper and better depends largely on local conditions. A properly designed and honestly constructed reinforced concrete tank will hold heavy oil without trouble and there are hundreds of them in service but under most conditions steel is cheaper and more satisfactory, especially for large tankage.

RELATIVE PRICE OF OIL AND COAL

During the past summer, fuel oil has sold at New York and Baltimore at approximately $1.25 a barrel. In New England it is slightly more and in the South less expensive. Reference to Table 1 will enable one to compare oil and coal on a basis of fuel costs alone. The relative operating expenses will, of course, depend entirely upon local conditions at the plant in question. While it is impossible to predict the future course of prices, the oil market seems to be back on a peace basis now and fairly well stabilized, with many oil companies delivering fuel oil and making contracts. Ocean freight rates make up the greatest part of the cost of fuel oil and these seem to have reached their peak. Coal prices will of course move with the price of rail transportation and miners' wages. Certainly until conditions are greatly changed every month will see more plants equipped to burn fuel oil by owners who are awake to the possibilities of this modern fuel.

No. 552

FUEL OIL EQUIPMENT

By John P. Leask[1], New York, N. Y.

Non-Member

THE term "fuel oil," as mentioned in this paper, is confined solely to the reduced Mexican oil of approximately 14 deg. baume as this is the type of oil best suited for fuel on the Atlantic seaboard. The advantage of using this type of fuel may be summarized briefly as follows:

1. Less storage space is generally required for same amount of heating value.
2. No deterioration of fuel in storage.
3. Fuel can be stored in any desired location and need not necessarily be in close proximity to boiler room.
4. No danger of property loss due to spontaneous combustion.
5. Fuel is always dry, ready for use and not frozen solid as is the case with coal stored in open piles in northern climates.
6. Fuel is placed in storage and moved from storage to boilers with minimum labor charges.
7. Increased efficiencies are obtainable on boilers.
8. Increased ratings are obtained on boilers.
9. Boilers are easily adjustable to varying loads.
10. Less labor is generally required in boiler room.
11. No charges for ash handling, ash cans, conveyors and fire tools.
12. Increased life of furnaces.
13. Less stack area is required.
14. In new plants installation costs are generally less, leading to lower fixed charges.
15. No losses due to banked fires.
16. Less wear and tear on surrounding machinery, due to absence of dust, grit, etc.

In considering these advantages of fuel oil, however, it must not be understood that every plant that is now burning coal can be placed on a fuel oil burning basis to good advantage. Unless there is some compelling reason for burning oil rather than coal, it is not

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in every case good economy to change over a plant. Before an owner decides definitely to place his plant on fuel oil he should be reasonably certain that he will obtain a fair return on the money invested in new equipment. This applies primarily to plants which are now burning coal, as in cases of new installations this return can almost always be shown.

One of the first questions which arises in this connection is how many gallons of fuel oil will be required to do the work now done by a ton of coal. The most satisfactory way to obtain this comparative figure is to start with the number of pounds of water evaporated over any pre-determined period for which the coal consumption is known. With this figure as a basis, and knowing that under normal operating conditions, 1 lb. of fuel oil will evaporate 15 lb. of water, the number of pounds of fuel oil required may be determined. This, in connection with the number of pounds in a gallon of oil of the specific gravity to be used, will give the number of gallons required.

Another method of calculating this figure is by taking into consideration the relative efficiencies obtained and the relative calorific values of the two fuels. Several tables have been published giving the number of gallons of fuel oil equivalent to a ton of coal under varying conditions.

Table 1 gives the evaporation per pound of coal from and at 212 deg. fahr. and the number of gallons of oil equal to a ton. Fuel oil is taken at 18,640 B. t. u. per lb. and 8 lb. per gallon. Two net efficiencies are given for fuel oil. Whichever one is desired may be used. The table is also arranged to give the gallons of oil equivalent to both long and short tons.

It might be stated, however, that the efficiencies of 71 per cent and 75 per cent of boilers operating on fuel oil are easily attainable as has been demonstrated on repeated tests. This calculation will show the relative amounts of fuel required, and when the price of fuel oil at the destination under consideration is applied to the calculation, the relative costs of the two fuels will be obtained.

When the cost of coal is considered, it must be borne in mind that this cost must include all handling and trimming charges in bin, plus all labor charges getting the coal to the boiler room, plus all handling and cartage charges for removing ashes. The labor item for attendance to boilers can always be reduced, provided more than one man has been necessary on a shift. Also if automatic machinery is used on the coal-fired installation, all fixed and maintenance charges on this apparatus must be added to the cost of coal.

Fuel oil installations may be divided into two classes—(1) those requiring large storage capacity and receiving their oil from tank cars and barges and (2) those dependent upon tank wagon delivery where present conditions make the amount of storage necessarily small.

In plants in the first class, the amount of storage depends upon the decision of the management as to how much storage is advisable.

In arriving at this conclusion, however, several factors should be considered among which can be mentioned:

1. Maximum oil consumption over any period.
2. Distance to station supplying oil.
3. Transportation problems. Will shipments arrive quickly?
4. How will oil be shipped? In barges or cars? (In this connection it must be remembered that sufficient capacity should be provided to leave a safe working margin at the time when the next shipment is due.)

Oil is stored either in above or below ground tanks, which may be built of steel or concrete. These tanks must be properly vented and provided with heating coils so that the oil may be kept at proper viscosity to be pumped.

Overground tanks should be surrounded by concrete, masonry, or earthen dikes, to prevent oil from flooding neighboring property should a leak occur in the tank. If overground tanks are used, the oil should be taken from the storage tanks to an underground working tank which, for convenience, should have capacity to handle the plant at maximum load for a period of at least 8 hours. The working tank is provided so that the supply of oil to the burners may be below the burner level making it possible to drain all lines back to the working tank and absolutely preventing a gravity flow to the burners.

From the working tank on, the two cases are the same, as the oil is taken by pumps from this point and supplied to the burners.

In the second class, which generally embraces office buildings, hotels, and similar structures, the storage tank is usually made as large as the available space and local fire restrictions permit. It is always advisable to store one week's supply and the capacity of the tank must be such as to take a full tank wagon and still have a working stock. It is desirable in installations of this class to place the tanks underground, but this is usually out of the question in existing structures. The tank is then placed on the lowest floor and erected in accordance with local rules. Cylindrical tanks are preferable due to their lower cost, but the available space can generally be used to best advantage by using rectangular tanks. In either case, the tank must be of sufficient strength to withstand the pressure created by having the fill pipe full of oil to the street level.

If the tank is underground, the connections to the pump must be so arranged that the oil cannot flow by gravity to the pump and if the pump is lower than the tank some anti-syphon device must be provided to prevent the oil flowing to the boiler room should the suction connection to the pump become broken.

From the tank, the oil is taken by the pump and supplied to the line to the burners. This pump should be of the steam-driven duplex type and should be designed to handle this class of oil. As the boiler house is generally the heart of the plant, it is by far the most economical plan to supply these pumps and the necessary heaters in duplicate. The reasons for this are so obvious as to need no explanation.

TABLE 1[1]. GALLONS OF FUEL OIL EQUIVALENT TO A TON OF COAL

18,640 B.t.u. Per Lb. Fuel Oil (8 Lb. Per Gal.)

Equiv. Evap. from and at 212 deg. fahr Lb.	71%		75%	
	2,000 lb. Gal.	2,240 lb. Gal.	2,000 lb. Gal.	2,240 lb. Gal.
5.0	92.	103.	87.	97.
5.1	93.	105.	88.	99.
5.2	95.	107.	90.	101.
5.3	97.	109.	92.	103.
5.4	99.	111.	94.	105.
5.5	101.	113.	95.	107.
5.6	103.	115.	97.	109.
5.7	104.	117.	99.	111.
5.8	106.	119.	101.	113.
5.9	108.	121.	102.	115.
6.0	110.	123.	104.	117.
6.1	112.	125.	106.	119.
6.2	114.	127.	108.	120.
6.3	115.	129.	109.	122.
6.4	117.	131.	111.	124.
6.5	119.	133.	113	126.
6.6	121.	135.	114.	128.
6.7	123.	137.	116.	130.
6.8	125.	140.	118	132.
6.9	126.	142.	120.	134.
7.0	128.	144.	121.	135.
7.1	130.	146.	123.	138.
7.2	132.	148.	125.	140.
7.3	134.	150.	127.	142.
7.4	136.	152.	128.	144.
7.5	137.	154.	130.	146.
7.6	139.	156.	132.	148.
7.7	141.	158.	134.	150.
7.8	143.	160.	135.	152.
7.9	145.	162.	137.	153.
8.0	147.	164.	139.	155.
8.1	148.	166.	141.	157.
8.2	150.	168.	142.	159.
8.3	152.	170.	144.	161.
8.4	154.	172.	146.	163.
8.5	156.	174.	147.	165.
8.6	158.	176.	149.	167.
8.7	159.	179.	151.	169.
8.8	161.	181.	153.	171.
8.9	163.	183.	154.	173.
9.0	165.	185.	156.	175.
9.1	167.	187.	158.	177.
9.2	169.	189.	160.	179.
9.3	170.	191.	161.	181.
9.4	172.	193.	163.	183.
9.5	174.	195.	165.	185.
9.6	176.	197.	167.	187.
9.7	178.	199.	168.	188.
9.8	180.	201.	170.	190.
9.9	181.	203.	172.	192.

[1] From the August, 1919, issue of the *Atlantic Lubricator*.

TABLE 1—(*Continued.*)

Equiv. Evap. from and at 212 deg. fahr. Lb.	71%		75%	
	2,000 lb. Gal.	2,240 lb. Gal.	2,000 lb. Gal.	2,240 lb. Gal.
10.0	183.	205.	173.	194.
10.1	185.	207.	175.	196.
10.2	187.	209.	177.	198.
10.3	189.	211.	179.	200.
10.4	191.	213.	180.	202.
10.5	192.	215.	182.	204.
10.6	194.	218.	184.	206.
10.7	196.	220.	186.	208.
10.8	198.	222.	187.	210.
10.9	200.	224.	189.	212.
11.0	202.	226.	191.	214.
11.1	203.	228.	193.	216.
11.2	205.	230.	194.	218.
11.3	207.	232.	196.	220.
11.4	209.	234.	198.	221.
11.5	211.	236.	199.	223.
11.6	213.	238.	201.	225.
11.7	214.	240.	203.	227.
11.8	216.	242.	205.	229.
11.9	218.	244.	206.	231.
12.0	220.	246.	208.	233.
12.1	222.	248.	210.	235.
12.2	224.	250.	212.	237.
12.3	225.	252.	213.	239.
12.4	227.	254.	215.	241.
12.5	229.	257.	217.	243.
12.6	231.	259.	219.	245.
12.7	233.	261.	220.	247.
12.8	235.	263.	222.	249.
12.9	236.	265.	224.	251.

At the outlet of the pump there should be provided a relief valve for returning the oil to the tank should the pressure become excessive. The pump should also be provided with a governor for controlling its speed by the amount of oil it is called upon to deliver, and a gage for indicating the pressure against which the pump is operating.

From the outlet of the pump, the oil is delivered to the heaters. These heaters are designed so that the steam surrounds the heating element through which the oil passes. It has been found by experiment that this arrangement is the most satisfactory and it has also been demonstrated that those heaters in which the heating element is in the form of a coil are the most efficient. In heaters of the straight tube type, the outer film of oil becomes heated first and acts as a lubricant permitting the inner core of oil to pass through without becoming heated. In burning fuel oil uniform temperature is an absolute essential, so that it can be readily understood that the selection of the proper type of heater is vitally important. Thermometers should be provided to indicate the temperature of the oil entering and leaving the heater.

The pumps and accessories together with the heaters and accessories are generally combined in a combination pump and heater unit. In this unit the heaters are mounted horizontally and the pumps are mounted above them. This makes a compact and accessible unit and should be so arranged that either pump may be used with either heater, and so that either live or the exhaust steam from the pumps may be used in the heaters as a heating medium. In burners of the steam or air-atomizing type, the exhaust steam from the pumps will generally be found sufficient to heat the oil.

When it is considered that the pump and heater unit is the most vital part of the installation, it can be seen that it is poor economy to install inferior equipment at this point. It is the wisest course to put in the best equipment obtainable for the work as this unit will probably be in operation for a long period.

From the heater, the oil passes through the line to the burners. On this line may be installed automatic valves, strainers, meters, and other accessories, but as these items are not absolutely necessary in well designed systems they will not be discussed.

The end of the line conveying the oil to the burners should be provided with a valve and return line to the tank for the purpose of circulating the oil at such times as it may become cool or when the plant is starting operation.

The oil passes into the furnace through a burner. It is upon this burner that the proper operation of the furnace depends. Burners may be divided into several classes, according to the medium used for atomizing the oil:

1. Mechanical atomizing burners.
2. Burners using high pressure air for atomizing.
3. Burners using low pressure air for atomizing.
4. Burners using steam for atomizing.

Burners of the first class have found their chief field of utility in marine work. The high temperatures and high pressures required on the oil, the very small orifices necessary, with the consequent necessity for a series of strainers, and the special furnace fronts required, do not make them desirable for use in locations where fresh water is easily obtainable.

Burners of the second class, while yielding slightly higher efficiencies than steam-atomizing burners under test conditions, require the installation of expensive compressors and cannot be operated as cheaply as steam-atomizing burners.

Low pressure air burners are the ideal burners for industrial furnace work, where the oil consumption is low, a certain class of flame is required, and close regulation is of paramount importance.

Where large quantities of oil are to be burned, however, and where the steam to be used for atomization can be taken close to the source of supply, as is the case in boiler plants, the steam-atomizing burner has proven the most satisfactory. Many thousand burners of this class have been patented but the number which deserve serious consideration is very small.

The main points to be considered in choosing a burner for use are

as follows: What is the steam consumption? This figure is usually given in percentage of water evaporated; a figure which necessarily takes into consideration the efficiency of the boiler. From the manufacturers' standpoint, the .burner should be rated according to the number of pounds of oil atomized per pound of steam used. It is obvious that the same burner operating under identical conditions on two boilers, one 50 per cent efficient and the other 80 per cent efficient, will require varying percentages of steam for atomization, dependent upon whether the boiler is clean or dirty. This steam consumption is a very important factor. In one instance which has come to our attention the difference of 1 per cent in steam consumption made a difference of $12,000 per year in operating costs.

The oil orifice in the burner should be amply large so that an extensive series of strainers is not necessary and so that it does not have to be cleaned at frequent intervals.

The steam orifice should be small so that full advantage may be taken of the velocity of the steam and should be so constructed that the wear is reduced to a minimum.

The burner should be so constructed that the steam emerges under the oil and is used to support the oil. There should be no chance for steam to coke the oil inside the burner.

The burner should also be so constructed that it can be easily cleaned if necessary and so designed that parts subject to wear can be easily replaced. It should be readily adaptable to the particular boiler under consideration. It should not be necessary to arrange the boiler to suit the burner. All first class burners are supplied with an oil cock so that the supply of oil can be readily controlled. All the above points are important in selecting the proper burner.

The design of the furnace is of great importance, if high efficiencies are to be obtained, and this should be done by engineers with experience on this class of work. As a general proposition, however, it might be said that boilers of the return tubular type and water tube boilers which are horizontally baffled, are best fired by removing the grates and bridge-wall and firing the burners from the front toward the rear. Boilers being erected today are usually set high enough so that the grates may be left in, but in existing installations this rarely is found. In boilers which are vertically baffled, it is generally advisable to remove the grates, leave the bridge-wall in place, and in all other respects fire as in h. r. t. boilers.

The air for combustion should be admitted below the center of the flame and this may be done in a number of ways.

It has been said and is a fact, that, while higher efficiencies can be and are obtained with oil fuel, it is nevertheless possible to burn oil with great waste. This is true, but if this condition exists the fault lies with the plant manager and not with the fireman. With draft gages in working order and some method of taking flue gas analyses, and with proper instructions to the operators as to the uses of these instruments, and how they indicate the efficiency of the furnace, there is no reason why fuel oil should not remain, in the mind of every user, the ideal fuel.

No. 553

OIL FUEL VERSUS COAL

By David Moffat Myers[1], New York, N. Y.

Non-Member

OIL is almost an ideal fuel. It is the most beautiful fuel from an engineering standpoint with the exception of natural gas. Like natural gas, its supply is distinctly limited. One estimate gives 20 to 25 years as the probable period that oil fuel will last. It should, therefore, be applied to very special uses where its natural characteristics are distinctly and specially in demand, as in naval and certain classes of marine practice and for special processes, etc. It should not indiscriminately be burned and wasted as our present coal supply is, and has been, for many years.

If oil were sufficiently plentiful and cheap, and if a constant and steady supply could be guaranteed with certainty, it would of course be an ideal fuel to apply in our office buildings, large apartment houses and hotels in cities, as well as throughout the country in our industrial power plants and central stations. But oil is neither plentiful nor cheap, and a constant or steady supply cannot be relied upon except in a comparatively few favored localities.

The requirements for safety for oil must be very stringent. Note, for instance, the rules and regulations for oil storage and utilization recently issued by the Bureau of Standards and Appeals of New York City.

Although oil contains 18,000 to 20,000 B. t. u. per lb as against 13,500 to 14,500 B. t. u. per lb. for soft coal, yet, owing to the space requirements for protection of the oil, the city regulations are such that in 1,000 cu.ft. of space 25 tons of coal may be stored, whereas this space will only accommodate 15 tons of oil. 25 lb. of coal at 14,000 B. t. u. gives 350,000 B. t. u. relative storage. 15 lb. of oil at 19,000 B. t. u. gives 285,000 B. t. u. oil storage. Thus, in the same space, 22½ per cent more heat units can be stored if coal is used. This is important in office buildings where even with coal perhaps only two or three days' supply can now be stored. Substituting oil would cut down the amount of this fuel storage. Furthermore, while New York City regulations permit the placing of oil tanks in existing coal storage vaults, it is hardly a wise policy to do so as this would result in shutting off the possible use of coal.

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The supply of oil is uncertain. The principal field from which oil is available in New York at the present time is Mexico.

Under equally favorable conditions, it is true that a somewhat higher thermal efficiency can be obtained with oil than with stoker-fired soft coal. On the other hand, an oil fire may be flooded with a tremendous excess of air without indicating the fact to the operator, as a coal fire would under the same conditions. It is really easier to fail in the efficient operation of oil than with coal, so that in the long run, especially in small plants, it is quite possible that the efficiency with oil might run below that which would probably obtain with coal. In a recent examination of a plant, there was found an extravagant waste of oil on account of the reasons just stated. It is perhaps fair to state that the same thermal efficiency is obtainable with either oil burners or stokers. On this basis, Table 1 has been prepared to show the fuel cost of oil and coal per 1,000 lb. of steam at different prices for the respective fuels.

This table does not take into account any other cost than fuel cost; the labor, overhead, etc., is not considered in the computation. For a quick calculation of this kind, one may double the price of oil in cents per gallon, call this dollars per ton of coal, and obtain the equivalent price for the same steam capacity with either the oil or the coal. For example, if oil is 4¼ cts. per gal., coal at $8.50 per ton would give the same fuel cost for evaporating 1,000 lb. of steam.

If it happens to be the case that conditions assure us of a thermal efficiency with oil 10 per cent higher than with coal, then we may substitute the long ton for the short ton in Table 1 and our comparison will be approximately correct.

The labor of ash handling with oil burning is, of course, entirely eliminated. In the small plant, however, it would frequently be impossible actually to save any money as the time of one man could not be eliminated even if ash handling had become unnecessary. In large plants, on the other hand, it is possible that a considerable labor saving can be made by the elimination of the handling of ash. For the sake of safety in any boiler plant at least two men should be on the job so that the apparent saving of labor does not always reflect itself in money saving.

Owing to the extremely small supply of oil as compared to coal, the former fuel should be used, as has been previously indicated, for special purposes which require its advantages, and it is evident that it should not be consumed wastefully. In the average office building in this city not over 4 or 5 per cent of the heat energy in the fuel as fired is converted into electrical energy at the bus-bars. It seems a crime to consume so rare and valuable a fuel as oil with a heat loss of 95 per cent. It is bad enough to do this with cheaper coal of which there is an infinitely greater supply. Of course during the heating season, when possibly as high as 60 per cent of the original heat value of the fuel is rendered useful by the application of exhaust steam to heating and process, the case takes on a different aspect.

Putting the matter in a few words, it is improper and economically wrong to use fuel oil at a loss of 95 per cent, as would be the case in the ordinary power plant wasting its exhaust steam. Even in the highly developed central station, the average efficiency is not over 10 or 15 per cent, and here again it seems a very wrong thing to waste this wonderful fuel with the 85 to 90 per cent loss which would be involved. A legitimate use of fuel oil, in connection with the generation of energy, would be through the medium of high economy oil engines which develop thermal efficiencies from 25 to 34

TABLE 1[1]. COST OF EVAPORATION WITH VARIOUS FUELS

Fuel	Price per Unit	B.t.u. per lb.	Efficiency of Boiler and Furnace	Net evaporation from and at 212° per lb. or cu. ft.	Fuel cost to evaporate 1,000 lb. steam from and at 212° F.
1—Bituminous	$4.00 per 2,000 lb.	14,000	Hand-fired 63%	9.10	$0.22
2—Bituminous	$5.00 per 2,000 lb.	14.000	Hand-fired 63%	9.10	0.275
3—Bituminous	$4.00 per 2,000 lb.	14.000	Modern Stoker 73%	10.55	0.19
4—Bituminous	$5.00 per 2,000 lb.	14,000	Modern Stoker 73%	10.55	0.238
5—Small Anthracite	$2.00 per 2,000 lb.	12,000	Hand-fired 60%	7.43	0.135
6—Fuel Oil	$0.05 per gal. (7½ lb. per gal.)	18.500	73% Oil-burners 73%	per cu ft. 13.92	0.478
7—Fuel Oil	$0.04 per gal.	18,500	Oil-burners	13.92	0.382
8—Fuel Oil	$0.03 per gal.	18,500	73% Oil-burners	13.92	0.287
9—Fuel Oil	$0.02 per gal.	18,500	73% Oil-burners	13.92	0.191
10—Natural Gas	$0.30 per 1,000 cu. ft.	1,000 B.t.u. per cu.ft.	73% Gas-burners	0.753	0.398

NOTE: The fuel oil at 2 cts. a gal. is equivalent in fuel cost to coal at $4,00 per ton of 2,000 lb. used with modern stokers. The fuel oil at 3 cts. a gal. is equivalent in fuel cost to coal at $6.00 per ton of 2,000 lb. used with modern stokers.

per cent, but the indiscriminate use of oil at a huge waste, although a slight financial saving may be obtained, re-acts directly against the conservation of our natural resources. Such use is therefore to be discouraged.

It is probable, however, that not much "discouraging" will be necessary. I recently endeavored to secure a supply of fuel oil for one of the legitimate cases, for a plant just outside New York City limits above the Bronx, and found it impossible to obtain a contract from any of the oil companies. These companies were unable to say how soon they would be able to make any further contracts and in any event did not wish to consider guaranteeing a supply for

[1] From *Power Plant*, by David Moffat Myers.

more than a three-months period. One stated they might, at some distant time, give a one-year contract.

Now, to install an efficient and suitable oil burning equipment with storage facilities at all comparable with coal, costs as much as a first class automatic stoker installation. Who wants to go to that expense with the possibility of having to discard the installation in three months or a year?

In a plant recently reported upon, two out of four of the boilers had been badly bagged, blistered and strained to the leaking point shortly after oil burners had been installed. With improperly designed or badly operated furnaces, such occurrences are more than likely. The matter of safety, therefore, not only in connection with the storage of oil but also in relation to the burning of this fuel is of prime importance and requires the most careful consideration when the liquid fuel is adopted.

We have recently been called upon to report on the oil and coal situation in a very large office-building plant in Philadelphia which is to be constructed. Our findings may be briefly summarized as follows:

A. For the safe storage of oil an additional $60,000 would have to be spent of which excavation alone would cost $25,000.

B. Owing to the uncertainty in supply, it would not be safe to equip such a building to depend on oil exclusively. Consequently, a coal burning equipment would have to be installed in any event, and if oil were used it would be used only as an auxiliary fuel at such times when prices might favor its use.

C. No saving in operation at existing prices of oil and coal could be shown in favor of oil. In fact, the difference in operating cost favors coal.

This does not mean that there may not be a great many cases, as there undoubtedly are, where oil would be the more economical fuel to employ. In fact, we have recently reported in favor of oil for a certain industrial plant where a long contract for oil supply could be secured and where the labor situation was the deciding factor in the problem. In this plant, however, the exhaust steam was entirely utilized so that the over-all efficiency of the plant would be high and the oil would be economically applied.

A very popular and equally important way to emphasize the necessity of conserving fuel oil is to call to mind the necessity for fuel of this kind for the several million automobiles in this country. There is no other fuel in sight than petroleum or its derivatives for this service. This is an additional argument and a very strong one to emphasize the necessity for the most stringent conservation of fuel oil.

As before stated, oil is almost an ideal fuel. But there has been, and is prevalent, a vast amount of misconception regarding its advertised economies, and an ill judged enthusiasm in its favor has been aroused by those who are financially interested in its sale and promotion.

I have, therefore, in this brief statement endeavored to set forth some of the hard cold facts which should receive the careful consideration of all those who desire to reach a sound, unbiased solution of the problem, looking at the matter through the eyes of the owner of the plant.

OIL AS A FUEL FOR BOILERS AND FURNACES, By H. H. Fleming,

AND

FUEL OIL EQUIPMENT, by John P. Leask,

AND

OIL FUEL VERSUS COAL, by David M. Myer.

JOINT DISCUSSION

THE AUTHOR (H. H. FLEMING): The great number of oil burning ships that have been launched very recently, together with the large number of industrial plants converted to oil in the same period, have produced a condition where the demand for fuel oil is beginning to outstrip the construction of transportation facilities. This, of course, is only temporary for shipyards the world over are rushing the construction of tankers. However, it will be some months yet before many of these are completed and I understand that until more tonnage is available, most of the large oil companies are reluctant to contract for any large quantities of fuel oil beyond those which they are already committed to.

For this reason I wish to urge the advisability of making sure of the fuel supply for any particular plant before proceeding with any conversion of equipment.

W. C. McTARNAHAN[1]: Oil as a fuel is quite new on the Atlantic Coast, having been introduced here as a fuel under boilers within the last four or five years for general use. In California, however, I can remember the days when the cattlemen used to build fences around the pools of oil in what is now the vast California oil field. I have ridden over that country on horseback and have seen the barricades put up around oil seeps into which, if a steer happened to carelessly walk he gradually sank. Some of the old pioneers used to go out from Fresno, Visalia and other places, bring in this oil in what we used to call the coal-oil can, pour it onto the wood in the stove in the winter-time, getting a hot, crackling fire, making the wood last longer, and creating a very hot fire.

It was not very long before several men out there, among them Mr. Fessler, Mr. Hammell and other old government pioneer men, started in to develop apparatus to burn this oil. The first thing that was tried was steam of course. The burners were crude and steam

[1] Fess Oratory Oil Burner, Inc., Boston, Mass.

was used for atomizing purposes, breaking up the oil, heating it and blowing it into the furnaces. Those systems have been widely developed and are in use today very generally in high pressure steam plants.

That was very convenient, for there were no coal fields in California. Coal was brought from British Columbia, Alaska and other places at a high cost for very poor coal. The B.t.u. value of the ordinary western coal, British Columbia coal, Washington coal, is low—9,000 to 10,000 and it was not very long before a great many high pressure steam plants were using oil with varied success. The apartment house owner and the hotel owner and the office building owner soon wanted to enjoy this economy and saving of labor in removal of ashes and he called upon the fuel oil men, for an apparatus to use in heating plants.

This finally developed various types of burners. The first to come on the market was that formerly called a steam-generating burner. It consisted of a piece of two or three inch pipe with a small inner pipe with bushings. City water was turned into that through a needle-valve, and some oil run in the ashpit of the fire-box around this pipe. The oil when set afire generated steam. This apparatus was quite unsatisfactory, however, because the needle valve would get stopped up and it required constant watching.

Later, railroad air compressors of various types, electrically driven, were used, a three or four horse-power motor carrying the air at 75 or 80 lb. pressure was used to atomize the oil with headers to separate pumps, either electrically driven or gravity feed.

The art was further perfected as years went on, until finally manufacturers used a small motor, half-horse or three-quarter horse, for a small plant, say a 10,000 foot boiler, pumped the oil by means of either rotary pumps or worm reduction gears and mechanically atomized this fuel oil, doing away with the necessity of high pressure steam or high pressure compressed air.

In California there is a company which has between 5,000 and 6,000 installations, the greater part of them in low pressure plants. In fact it is today almost a curiosity to see in San Francisco or Los Angeles a coal wagon unloading coal in front of any downtown building. Although some coal is still burned, the amount is very limited. In residences more coal is burned, because there is as yet no satisfactory equipment to put into the ordinary residence, where the coal consumption is small, 10, 12 or 15 tons per year. Of course with residences of the larger type, that will burn 100, 150 or 200 tons of coal a year, the same type of low pressure apparatus can be utilized as in the average apartment house.

The use of fuel oil has now spread to the Atlantic Coast and I think I am conservative in saying that there has been wonderful progress made in the use of fuel oil on the Atlantic Coast as a substitute for coal.

The matter of fuel oil supply is of course very interesting just now. The logical and only source of fuel oil supply for the Atlantic Coast is Mexico. Until a few months ago, the American oil com-

panies enjoyed unrestricted privileges in Mexico as to drilling, operation and exportation or importation of oil into the United States. Then the Carranza government enacted a law which virtually confiscated the American oil man's property in Mexico if he drilled a new well. It simply said that if any new wells were drilled, the land belonged to the Mexican government, or at least everything below the surface of the ground. They gave the American man the sage brush and the top surface, but anything below the surface belonged to the Mexican government. This was a very disastrous condition, because the United States Shipping Board was depending on fuel oil to operate the ships and navy, and many large industries had converted their plants from coal to oil. It meant strangulation of the business and death to the oil interests unless this law or act was reversed. The oil interests put forth every interest to overcome this and within the last two weeks have received a temporary dispensation, at least till next September, with permission to go on drilling. At that time, the Mexican Congress will go in session, and I believe satisfactory legislation will then be enacted.

The oil supply of Mexico has not been scratched I know one tract of 460,000 acres of proven oil land which has oil seeps and oil bubbles and oil lakes pretty well all over it Drilling has proven that it is practically all oil productive territory. One of the largest oil wells, if not the largest oil well in the world, is in the center of this field. This is owned by one company and there are many, many other companies with large tracts of lands in Mexico that have not been touched. It is simply a matter of the United States Government standing up for the rights of the American property owners in Mexico who have spent millions and millions of dollars to carry forward this wonderful business of fuel oil. If an Englishman or a Mexican or a Frenchman or anybody else came into this country, paid his money and bought land, it would be his land, whether he wanted to mine on it, farm on it or build a building on it. He bought it and paid for it. We would not dream of enacting a law to take it away from him. But that is what is occurring in Mexico today; it will be deplorable if our Government allows it to go through.

Concrete storage for the use of fuel oil has proven to be very successful. Some 500 or 600 concrete oil storage tanks have been in use for several years in New England, and if the use of concrete oil storage tanks could be introduced in New York City it would greatly reduce the cost of installation as compared with the method now made necessary by the ordinance in use in New York specifying that steel storage tanks must be built with concrete tanks outside of them.

G. B. NICHOLS: Mr. Fleming's paper is one of the most timely submitted to the Society, on account of the great agitation now going on regarding the use of fuel oil in New York and vicinity. The agitation is touching the finances of every concern in New York City. It was only yesterday that I heard that it was proposed to pipe the lower part of New York City, leading the oil directly into all our main buildings, the same as gas or other utilities. Recently,

in the New England district, I ran across a financial interest that was proposing to install storage tanks up and down the Barge Canal from New York to Buffalo, making available fuel oil in that entire district. The agitation is going on in every power house in this district, and the owners are being approached by the oil companies, asking them to change over millions of dollars worth of equipment at the present moment. If the conclusions drawn are correct, it would mean the remodeling of all of the boiler plants in this vicinity, to put them on an oil-burning basis. I am not in any way opposed to this oil, but I think we ought to know all the fundamental facts, so as to draw our own conclusions.

In the opening paragraph the writer states, "Fuel oil has become available in large quantities and at lower prices than coal throughout the Atlantic Coast region." This is a broad statement and should be explained more in detail. I would like to ask for present quotations on oil at tidewater in the vicinity of New York Harbor and what guaranteed periodic deliveries and length of term of contract the oil companies will now enter into. I believe that is the keynote of the situation.

Reference is also made to plants being changed all along the Atlantic Coast to oil burning. At the present time what large plants in and about New York are changing over to oil burning and for what basic reason? It would be interesting if the Society could be given information regarding the operation of some of these plants which have been in service for some time.

Relative to the availability of oil in the Mexican fields, I mention the Carranza decree and its results and effect upon the production for use along the Eastern Coast. I understand Mexico will supply fully 75 per cent of the demand for this region. Mexico is a foreign country whose natural resources are subject to her own control, which, based on past diplomatic relations between that country and this, might be very indifferent to our demands. I understand that England is also depending upon a large percentage of the Mexican supply to meet her demands.

Granting, however, that conditions might exist which would allow these wells to yield their estimated potential production, we must carry in mind that the coal fields of Pennsylvania and the middle western states are already open to the entire world and will endeavor to maintain the present supply of coal as a fuel for industrial power and heating. This would mean, if the production of coal and oil allowed, that there would be a competition between these two fuels in supplying the nation's demands. Would not these widely separated fields tend to divide this country into zones in which the use of one kind of fuel will be fixed, depending upon proximity and transportation facilities? I feel that this is quite inevitable and in connection with the division of this country into fuel zones, I believe this should be done by the Bureau of Mines after making a through study of the conditions from the standpoint of conservation of this nation's resources. To date, however, oil burning developments seem to have been practically ignored. I have addressed

several communications to the Bureau of Mines, concerning oil burning data with negative results.

Thus far, we have considered that coal and oil could be placed on a competitive basis from an economic and operative point of view and have merely questioned Mr. Fleming's views on the availability and development. We will pass on to the advantages of fuel oil and take up the points which he enumerates as decidedly in favor of fuel oil.

Labor.—In a modern plant equipped with coal and ash handling apparatus and mechanical stokers, I maintain no labor could be saved by the use of a fuel oil installation. For example, I quote a certain power company which burns 400 tons of coal each day, employs 15 men for the total 24 hours in the boiler plant, five of whom are repair men and two ordinary laborers. Oil burning requires more attention, more tampering with and necessitates more skilled firemen than stoker installations, for with oil there is absolutely no automatic control, the action in itself is very unstable and its efficient combustion has not to date been made foolproof but, as previously stated, requires constant observation of atomization and per cent of air admitted.

Some may say that we have these automatic controls. I fail to find them. At the most recent installation I have looked at, the Narragansett Bay Company at Providence, which has been quoted in a number of trade journals within the past six months, they have equipped two 600 h.p. boilers with no automatic features at all.

Flexibility.—No greater margin of capacity can be obtained with oil than with stokers and the deteriorating effect of operating at high percentage overloads is much more pronounced with oil and a great deal more skill is required to maintain efficient combustion of fuel.

Waste of fuel in standby losses seems to exactly balance. These losses are principally due to radiation from boiler settings, at times when the boiler is out of service, and would be no greater for coal than for oil and equal amounts of fuel would be consumed in heating the settings to the normal temperature of operation. More time may be required with coal operation; at the same time the detrimental effect on brickwork is greatly reduced. If fires are run light I do not believe there is any saving in either installation.

Combustion.—Mr. Fleming declares that with the combustion of oil there is no smoke, no clinker, that there is no lack of steam from cleaning fires; hot fires can be maintained as readily as slow fires; that plants may be operated more closely to their test capacity. These points are all given as greatly in favor of oil operation and I will take each one separately and compare the result of the two fuels.

Smoke consists of visible properties, solid constituents and gaseous constituents. Its prevention is perfect combustion, which can be maintained more readily under varying conditions with coal than oil. The chemical constituents of smoke of the two fuels are very nearly the same, varying only slightly in percentage.

Oil does form a clinker which can only be removed when hot, as it forms a very hard scale when cool. Soot formed by burning oil

has the same effect on the thermal conductivity of tubes as that of coal. Due, however, to the intense heat of oil burners, more attention must be given to the removal of the soot in order to prevent accidents.

Hot fires necessary to carry overloads with oil fuel require no more physical exertion but require more constant watching. In order to produce complete combustion, overloads with coal require more frequent filling of hoppers but do not require the attention of expert firemen to produce complete combustion.

Coal fires if properly cleaned do not incur sudden drop in steam pressure even with poor grades of coal. Some cleaning must be done to remove clinker in boilers burning oil fuel. This does not have to be done very frequently, however.

Efficiency of Operation.—From 5 to 10 per cent higher efficiency can usually be obtained from oil over coal. I doubt very much if efficiency of over 82 per cent can be maintained. Some engineers operating plants equipped with oil burning equipment even go so far as to say they have not been able to make any gain in efficiency.

There has been a reference made here to the costs of these installations. This item necessitates a large initial expenditure on power plants. For instance, in the plant that I spoke of at the Narragansett Electric Light Company, which has two 600 h. p. boilers in operation, the boilers are being successfully run at 100 per cent overload. In fact, they are burning oil all through Providence, and that section. Those two boilers were equipped with one storage tank of slightly over a 1,000,000 gal. capacity. The contract price for the tanks without any connections—and that price must be based on at least the price of the market five or six months ago—was $34,000. Undoubtedly, if one were to purchase that 1,000,000 gal. tank today, it would cost $90,000. On that basis, a plant running 1,000 h. p., carrying 90 days' storage, would require practically $60,000 for the tank.

As a brief summary of the items brought forth in Mr. Fleming's article, I believe that if an equal amount of attention were given to the economical and efficient combustion of coal, as given to the oil proposition, most of the items as stated decidedly in favor of oil operation would be equally in favor of coal.

S. J. BROWN: The steamer Trojan, which in the summer time plies between this city and Troy, is now being converted into an oil burning ship. Her sister ship, the Rensselaer, is to remain a coal burning ship. Those two boats on alternate days will be at Pier 32, North River, New York City, and that would enable anyone interested in the subject to compare or contrast the relative virtues of the two systems if he so desired.

W. L. FLEISHER: In almost every installation on which I have been questioned on the advisability of installing oil burning equipment and in which the question of equipment and cost of equipment has come up, the possibility of getting oil steadily has been so uncertain that in three plants in which they have insisted on installing oil burning equipment, they also installed equipment for burning coal.

Now of course, if people put in both equipments there necessarily is not very much saving in the cost of equipment. That is probably a condition that has arisen with almost every one who has had anything to do with oil equipment under the present uncertainty of obtaining crude oil. Because of this condition, the engineer is asked in almost every instance how long it will take to change the furnace equipment so that coal can be burned if the furnace is equipped for burning oil. The oil companies and the oil equipment companies are likely to say that this is a question of no appreciable time, but my understanding of the fact is, that with the modern oil burning equipment, the bridge wall and grates are omitted from the boiler setting and in large boiler equipments the question of installing the bridge wall and grates is serious as under the best conditions it requires a week or more for their installation.

There is another question which comes up and that is the question of how much oil it would take to replace the coal now used for heating purposes in the United States. I have roughly approximated that this would be 3,000,000,000 bbl. of oil per year, and I do not think that the oil supply of the world today, either developed or undeveloped, would equal that amount. I feel that oil burning in large quantities is not feasible for the United States today, with conditions as they now exist.

I will bring up another point that is important : In a survey of the oil situation in the United States, I note that oil was first produced in Pennsylvania in 1859, and that all the wells that were operated in that period or even for 10 or 12 years after that, are practically useless today; that consequently the life of these wells about which we hear so much in Mexico is very limited. Nobody knows today just how long they will produce. I find that some of the Mexican wells that have been operated for not many years are decreasing in production and that all wells in any one area seem to be fed from a central supply. If there should be a 400,000 acre area in which the wells seem at first very prolific, after a certain period all the wells start to become depleted at one time. A situation of that kind, with which we are not familiar at the present time, is one to be very thoroughly investigated before we make statements as to the amount of oil that we can get out of any one territory. We are very apt in these days, to take everything that we can out of the ground as quickly as we can, without any idea of its life or without any idea of taking care of its conservation for future needs, or for more necessary uses.

I have brought up these points simply as a warning against rushing into such a radical change without thorough and satisfactory investigation.

THOS. BARWICK: With regard to the question of turning over the present plants to oil burning plants, it should be remembered that in most of the buildings in New York City the furnaces are very low. That is, the grates are set about 24 in. above the floor line and the boilers are set 24 in. above the grates. Now to get a proper combustion from oil we must have a deep and large furnace.

WM. H. DRISCOLL: The popularity of this oil burning question seems to result from the thought that there is an ample supply of oil in Mexico that can be drawn upon for an indefinite period. Now I have in my hands a copy of the regulations governing the burning of oil in the City of New York, which states: "Its specific gravity shall not be less than 0.933 or 20 deg. baume." If I have the correct information, there is no such oil in Mexico, or if there is, it is in such small quantities as not to be available for our purposes here. Of course I do not know how many other cities may have similar regulations, but I believe it is a fact, that one cannot burn the Mexican oil that we are discussing, in New York City today, because apparently the Bureau of Fire Prevention or the controlling departments assume that there are rather serious possibilities in connection with the storage of this oil.

In addition to that fact they place restrictions upon the storage which practically prohibit the burning of oil in any building. I would like to have an expression from some of the oil men here as to whether they think these are reasonable or unreasonable under the present conditions.

C. R. BISHOP: It seems to me that most of the talk we have heard so far today, on the fuel oil question has had a decided touch of pessimism, and I firmly believe from my own knowledge of the subject that statements have been made and impressions created that are far from correct. In answer to the question of the last speaker, regarding the rules and regulations prevailing in the City of New York concerning the use of oil as a fuel, I beg to advise you that previous to December 1st, 1919, the conditions were such that it was practically impossible to use fuel oil at all; during the preceding summer and fall very many meetings were held which resulted in the adoption of a new set of rules and regulations by the Bureau of Standards, etc., which have made it quite possible to store and use fuel oil. The rules and regulations as they stand at present are very far from perfect, nor are they entirely satisfactory, but they are a very decided step forward and no doubt, at some later date, will be amended to conform more nearly with the rules and regulations in effect in other cities. One of the most discussed conditions seemed to be the fire risk, yet I am advised that the investigations of a very large number of fire insurance companies, made after the great earthquake and fire which occurred in San Francisco a few years ago, brought out the fact that the buildings which had been using fuel oil to manufacture power and heat did not burn because of using oil; when the oil tanks and boiler settings were knocked down by reason of the earthquake, the fires were extinguished because without proper atomization or proper vaporization, fuel oil will not burn.

In the buildings using coal as fuel, the hot coal was scattered setting fire to the buildings.

I think at the present time, under the prevailing prices for fuel oil, many well equipped and managed large power plants could do nearly as well if they continued to use the high grade anthracite coal which they are getting under favorable contracts entered into some time

ago, but it is of unquestioned advantage to many apartment houses, hotels and particularly residences to use oil as a fuel. In such classes of buildings coal is being burned most inefficiently and the highest prices are being paid for coal. In large power plants a very great saving in the cost of labor is obtained by using oil. I heard it stated recently that one of the large transatlantic steamers had been able to reduce the number of men employed in the boiler room and in the handling of fuel to the extent of nearly 300 by changing from coal to oil as a fuel.

Most of the available Mexican fuel oil is 14½ deg. to 16 deg. baume, and is very viscous, hard to handle and, particularly during the winter, has to be pre-heated before it is passed to the burners. It is stated that in Providence most of the fuel oil used comes from Mexico. I am advised that during the first 11 months of 1919 more than 3,000,000 bbl. of fuel oil were used at Providence, almost entirely in the generation of power and light. To give some idea of the quantity of fuel oil required for heating work in a district of New York City, I will state that data have been secured covering the quantity of steam required for heating that section of the city bounded by 69th Street, Central Park, 135th Street and the Hudson River. The district contains approximately 9700 buildings, which would require during the heating season about 2,500,000 bbl. of fuel oil; the maximum day's consumption would be approximately 16,000 bbl. From such information, it is to be noted that a very great amount of heating and small power work can be done without using a very large amount of fuel oil. I have heard it stated that the New York Steam Company would use about 1,000,000 bbl. of fuel oil annually if oil were substituted for anthracite coal.

None of the papers has referred to refining companies as a source for obtaining fuel oil, therefore I would call attention to the fact that last summer one of the distributing companies contracted with a refining company for a 100,000,000 bbl supply to cover a period of 10 years, and it is not at all unlikely that large supplies of fuel oil can be obtained from the same and other eastern refineries.

Permit me to quote from one of the papers presented, and published in the January Journal of this Society: "A very popular and equally important reason for emphasizing the conservation of *fuel* of this kind is for the several million automobiles in this country. There is *no other fuel* in sight than petroleum or its derivatives for this service. This is an additional argument and a very strong one to emphasize the necessity for the most stringent conservation of fuel oil." The two principal oils used by automobiles are gasoline and lubricating oil, both of which are taken from crude oil, not from fuel oil. Crude oil is the oil as it comes from the wells and it contains many volatile oils as well as lubricating oil which, extracted by refining, leaves a residuum known as fuel oil. The baume of fuel oil is generally between 13 deg. and 29 deg.

The day before yesterday I had an opportunity to see a recently designed low pressure fuel oil burner, designed with particular reference to use in connection with house heating boilers. It does not

require oil pumps nor air compressors, is inexpensive and can be placed without alteration in the fire box of the boiler. It was operating under a 1,000 ft. American Radiator Company's boiler and producing a rating of 2,000 ft. It was using oil of about 25 deg. and evaporating about 14.3 lb. of water per pound of fuel oil consumed.

One speaker has stated that there is considerable expense and time lost whenever it becomes necessary to change from oil burning to coal burning; as to that feature I understand the W. N. Best Company, Inc., of New York and Brooklyn, manufacture an apparatus for use in connection with high pressure steam boilers which will permit their operation for an hour or so using gas, another interval using coal and at other periods using fuel oil or combinations of such fuels.

As to the production of oil, I believe the U. S. Government records show that up to January 1, 1919, there had been produced in the United States approximately 6,220,000,000 bbl. of oil, and that by applying the curves of average decrease in production of the then existing wells, there might yet be expected at least 7,000,000,000 bbl. of oil without taking into consideration wells yet to be brought in, so we cannot expect a shortage of oil for many years. Further, it is likely that many millions of barrels of oil will be produced from shale rock; this can be produced at comparatively low costs. The western shale rock oil contains a very high percentage of volatile oils and a very high quality of lubricating oil. In the production of shale rock oil a considerable quantity of natural gas is produced, an amount considerable in excess of that required in the process.

An official of the Mexican Petroleum Company recently stated that one of the Mexican wells had already produced about 45,000,000 bbl. of oil and the pressure still remained very high.

A MEMBER: What is baume?

C. R. BISHOP: Baume is the specific gravity of oil or the measure of its viscosity. Viscosity is the resistance to the motion of the molecules of a fluid body among themselves; opposed to mobility. It is in some respects analogous to sliding friction of solid bodies. The viscosity of oil diminishes as the temperature is raised. A 14 deg. baume oil is very viscous. There is a process or treatment by means of which a low baume oil may be given the apparent viscosity of, say 22 deg. baume oil.

H. H. FLEMING: It is rather difficult to reply to the discussions of my paper, because they are divided into two groups. Sometimes I notice one speaker takes both attitudes. One is that the advantages claimed for fuel oil are fictitious and for that reason there will be no demand for oil. The other is that the demand is so great that it cannot be supplied.

I think one thing that has been lost sight of, is that the use of oil for small plants in New York City, heating buildings, and for large power plants are two entirely different problems. If a plant has to go to the expense demanded by the New York City authorities,

which is much more than in any other place in the country, I believe, or if no labor will be saved, for instance in plants employing only one man, it is a question whether oil at the present prices would be cheaper than coal and better.

When we say the same results can be obtained with coal as with oil as to efficiency, etc., we have been talking about an expensive stoker installation, with ash handling equipment and all that goes with it. It has been said that with such a plant the same efficiencies can be obtained, and I believe they can on tests. It is also said that no more labor is required. In some cases this may be true, but we must charge for the stoker operation and compare the investment and upkeep of it and the ash handling apparatus. Those things must all be considered. We have been comparing in some of the discussion, the very best operation of coal with what can be done with oil. But a comparison of the two fuels in the average plant would seem of more value. The contention that more attention is required for oil I very much disagree with. It is said one can waste more fuel in burning oil because one is more likely to let in excess air. On the other hand, it requires very little attention and very little skill to keep the oil burning furnace up to efficiency, and no more labor than to run it wastefully. This is not true with the hand fired plant, and it certainly requires a greater amount of skill to keep a stoker plant or any fire bed in proper condition.

In comparing the cost of installation, I think there is no doubt that oil is cheaper in large plants, although not in small ones, bound by New York City regulations; for large plants the cost of storage tanks will run about $1 per bbl. of storage capacity. With coal storage, it is impossible to store on the same area an amount anywhere near the amount of oil, for the reason that a tank can be built 25 or 50 ft. high—that is the usual height—while coal must be spread out over great areas, and a cubic foot of coal will do only half the work of a cubic foot of oil. Besides tankage, the equipment includes only the small pumps and burners, with connecting piping.

If it should be an old plant, in which it is very expensive to change the furnaces, which is not usually the case, it may prove to be a very expensive conversion. Comparing the installation of the two plants, I think in 99 per cent of plants it will be cheaper to put in the oil tank, pipe line and burner than stokers, ash and coal handling equipment, etc.

It was asked what plants have been changed over around New York City. Well, the New York authorities evidently have not wanted any plants in the city to change, but outside New York City I now recall the Pacific Coast Borax Company, Bayonne; Warner Sugar Refinery, Jersey City; American Agricultural Chemical Company, with plants scattered from Florida to the northern part of Jersey; General Chemical Company; International Nickel Company; the Fleischman Company, Peekskill, putting in a plant that will use about a quarter of a million barrels a year; Spencer-Kellogg have oil in a couple of plants. This paper was written, as I said, six months ago, and the plants were changing then. So many have decided that the advantage of fuel oil is worth while, that the oil

companies cannot keep up with the demand at present until more tonnage is built.

As to the oil formation, etc., I would like to discuss the geology of oil, but I do not believe it will be possible at this time. It is very true that oil should be conserved but we would not be burning gasoline in fuel oil; with fuel oil selling at from $1 to $2 a bbl., a comparison with the present price for gasoline will show that there is not much gasoline being burned for fuel oil.

As to the regulation in New York City of not less than 0.933 specific gravity, there is no oil in Mexico of that nature. That is a very badly stated regulation; it says not less than 0.933 or 12 deg. baume. The difficulty is that the two scales go in opposite directions, so that "not less than 12 baume" means not heavier than 12; "not less than 0.933," means not lighter than 0.933. When these rules were being drawn up several petroleum engineers tried to make that point clear to the committee; the advice was not taken and the regulation worded as "not less than 0.933 or 12 baume, which is contradictory. I believe the intention was to specify the heavier oil.

Someone has asked whether the New York regulations are reasonable or not. My reply to that would be, that no other city in the country, including those which have burned oil for a great many years, have found it necessary, either by the record of their fires or by other experience, to approach the requirements made here, and I believe even the insurance regulations are not nearly so rigid.

I think that point of the difference between the smaller installation and the large should be emphasized. The small plant will save little labor. In one of the papers the cost of the two fuels per 1,000 lb. of steam was compared entirely on the B.t.u. value of the oil. The costs compared only on a B.t.u. basis we have found very misleading. It is the labor, handling, cost of installation, etc., in the big plant that makes a man want to use oil. I would not urge a small plant that can save nothing in labor and must comply with New York City regulations to change over unless the other advantages of the oil would mean a great deal to it, for it would cost it just about the same and in some cases, more. In the large plant the situation is really this; those who realized the advantages early enough to get contracts for two years, five years, or more, are the fortunate ones. Oil is the ideal fuel when it can be obtained.

W. C. McTARNAHAN: They say the proof of the pudding is in the eating of it. Men in New England and on the Atlantic seaboard who put in one plant four years ago are now the owners of 108, many of them seven and six and five repeat orders from the same people. Now, the man who is paying the bills certainly ought to know whether he is making any money or not, and he doesn't give a second order or a third order or a fifth order if the first one is a failure, if he is losing money on it. I want the privilege of reading four lines of this editorial from the Electrical Times: "With fuel oil at 10¾ ct. per gal., coal would have to reach a delivery price of $11 to $18 per ton before it could come into a competitive zone."

In substance it admits that oil at 10¾ ct. a gallon is a dangerous competitor of coal at $11 to $18 a ton.

Contracts are being made today and oil delivered by motor truck all over New England proper, that is, on the coast between Boston and Providence, at a base price of 4.3 ct. per gal., and at 5 ct. per gal. it is being hauled up to 15 mi. from station loading. We will take the coal man at his own word He says 10¾ ct. per gal. equals $11 to $18 coal, which is the range of coal given on the boat. Therefore, if we get oil at 5 ct. per gal. then we get coal from $5 to $5.50 to $9, which is the price of coal today; therefore the price at which oil is being delivered is in the safe competitive zone with coal today, from the coal man's own statement.

Another point I want to make is that we have just changed over a plant where the stoker apparatus and the ash handling apparatus cost some $80,000. We have converted that to oil. The plant burns only 60 tons of coal per day. Recognizing the fact that two or four men can handle 400 tons of coal a day, this plant is saving two men per shift on coal. They are doing various things to the upkeep of the plant, saving two men per shift on the job. If they charge off 10 per cent for depreciation and 7 per cent interest on the money, there is still a sufficient saving to pay for the plant in three years.

G. B. NICHOLS: A great deal has been said about the oil conditions in Providence, R. I., and I believe I am peculiarly situated regarding the comparison of oil in New York City and in the New England district, as I am doing business in New York City and my former home was in New England. The conditions of these two localities regarding oil are absolutely different. There is no question but that oil is being burned successfully in the New England district, particularly in Providence, R. I. Rhode Island, however, has suffered for the last four years in not being able to obtain coal for all purposes and was forced to use any available fuel. Providence is a seaport town and oil can be delivered to the heart of the City advantageously. Providence is a considerable distance from the coal mines and the price of coal is much higher than in New York City, the coal costing from 30 to 40 per cent more than in New York City. The comparison of coal is on a basis of $9.00 for soft coal as compared with $1.40 for oil. I have been definitely informed that a year ago the price of oil was $1.25 which is now $1.40 per bbl. New England undoubtedly is in the oil district and oil can be burned advantageously. It, however, cannot be compared with the New York district, which is much nearer the coal mines.

S. J. BROWN: I move that the Chair appoint a committee of three, consisting of heating experts, to investigate the conditions on the two river steamers of which I have spoken—they are exact duplicates in tonnage, they require the same horse-power for operation, they travel over the same route, under the same circumstances—the committee to report their findings as to the relative virtue of oil burning as against coal burning, at a subsequent meeting of this Society or to submit the same through the columns of the Journal at their convenience.

(The motion was seconded.)

MR. NICHOLS: I would like to amend it in this way: that the Bureau of Research investigate the subject of the burning of oil. I don't think we want to confine this to marine work. One of the best examples we have is the Narragansett Electric Light Company, which has changed over two large boilers to oil burning. You can get all the facts there. Let the Committee make a definite report of the entire subject. I amend it to that effect, that it be a general investigation of the subject.

H. B. GOMPERS: I believe that an experimental installation, approved by the Board of Standards and Appeals, is now in operation in the Singer Building, New York City. I might say in connection with this oil burning question, it all simmers down to one thing: you can't get any oil.

H. H. FLEMING: In regard to the amendment, if it is of any value—I would not be surprised if it was—to compare the value of coal and oil on ships, why not go to the United States Shipping Board, which has very complete records, and ask them what their experience was? They burn something like 30,000,000 bbl. a year and also a large amount of coal; they have very complete records, actual service records, not necessarily tests, and would be very glad to give them to you. I think that for marine work it would show up so much in favor of oil that it is hardly a fair comparison.

G. B. NICHOLS: In this investigation, we have two classes of engineering to investigate. First, there is the marine question with boiler plants aboard ship, in which one of the greatest factors is the possiblity of storing the largest amount of heating units in the hold of the ship. Second, the shore plants where this problem is not of vital interest. I think this Society should investigate both types of plants, reporting separately.

(The amendment was seconded and carried.)

W. C. MCTARNAHAN: There seems to be an impression prevailing that contracts for oil cannot be made. That is true in New York City today. It will not be true three months from now, as we are fast preparing to deliver oil in New York City. That is an absolute fact. A big plant is being built at Stamford, Connecticut.

Furthermore, in New England since 1915 we have been continually soliciting the installation of oil burning equipment and the delivery of fuel oil will not cease for one minute. They have been expanding as fast as plants could be built. There was not one plant installed there that ever went without oil. We went through the winter of 1917 and 1918, the worst ever seen for many years, when Providence Bay was frozen from Newport to Providence, and everybody got his oil fuel, when thousands of places were shut down in this city. Last night before I left my office in Boston I signed 18 contracts for fuel oil covering a period of six years. No one can tell me that we can't sell fuel oil, because trucks are delivering it today and we are conducting business throughout New England We are not taking it on in New York today because we cannot deliver it, but we can tell you that when we get the plant built it will be about 5 or 6 cents a gallon and it will be ready in about three months. These are facts.

No. 554

FOUR YEARS' EXPERIENCE IN PREVENTION OF CORROSION OF PIPE

By F. N. Speller, Pittsburgh, Pa. (Member)

and

W. H. Walker[1], Cambridge, Mass. (Non-Member)

An ounce of prevention is worth a pound of cure. So runs the familiar adage and never was its truthfulness more clearly demonstrated than in the case of the corrosion of steam piping, boilers, condensers and hot-water supply lines. Although we live in the age of preventive medicine where it is considered better practice to prevent disease than to allow it to occur and then cure it afterwards, the average engineer, so far as corrosion is concerned, follows the old and time-honored method. He drugs and physics his boiler to cure its ailments rather than to remove the cause and so prevent the trouble. Especially is this true in the case of the hot-water supply systems for large buildings, where the cost of replacement may easily be ten times the actual cost of the pipe renewed, yet no attempt has been made until quite recently to design such systems so as to minimize corrosion.

It is important that the engineer should have a clear idea of the reactions of corrosion. The modern conception of the chemistry of corrosion has been stated before in some detail but it may not be out of place to briefly review this subject without technical details.

THE MODERN THEORY OF CORROSION

Iron has a perfectly definite tendency to dissolve in water, with the separation of an equivalent amount of hydrogen. If there be no impurities of any kind present in the water, this solution proceeds to but a very slight extent. The surface of the iron becomes covered with a protecting layer of hydrogen and the action ceases. If free acid exists in the water, this hydrogen may be thrown off in the shape of a gas and the solution of the iron proceed with great rapidity. On the other hand, if an alkali such as caustic soda be added, not

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only is the acid neutralized and this action prevented, but the water itself is less active in its attack upon the iron.

Natural water, however pure it may be, is saturated with the oxygen of the atmosphere. While oxygen and iron do not directly unite except at a high temperature, yet the presence of oxygen dissolved in water has a controlling influence upon its ability to dissolve or corrode iron. This effect is produced by the reaction of the dissolved oxygen upon the hydrogen film, with which, in the absence of oxygen or free acid, the iron protects itself. Slowly but surely this hydrogen film is destroyed and the corrosion of the iron proceeds.

When the iron dissolves in the water, it exists in the difficult soluble form known as ferrous hydroxide. With this material, oxygen readily unites, forming the well known ferric hydroxide or rust. This formation of rust is a secondary reaction, and is a consequence and not the cause of the solution of the iron in the first place.

It is clear, therefore, that if all the dissolved oxygen be removed from water, the protecting film of hydrogen will not be destroyed, and the solution of the iron will cease. In other words, by taking out the dissolved oxygen, the cause of the continued corrosion is also removed. In any given amount of water in contact with iron, the dissolved oxygen content is therefore removed in two ways—first, the portion which unites with the hydrogen protective film, and second, that portion which unites with the ferrous hydroxide.

Considerable research work has been done to confirm this explanation of corrosion and to design practical preventive measures, principally by the chemical engineering department of the Massachusetts Institute of Technology and the research department of the National Tube Company.

PRACTICAL CONSIDERATION

It has been frequently observed that corrosion in boilers is more marked near the feed water entrance, and in hot-water supply systems is was found that over half of the free oxygen was removed by corrosion of the interior of the heater and that most of what remained was taken up by the pipes of the system before the water was drawn. It appeared from laboratory experiments, that corrosion practically ceased with elimination of free oxygen and is directly proportional to the oxygen content of the water, other factors such as temperature and amount of make-up being constant.

These facts led the National Tube Company to install in December, 1915, an experimental plant for the removal of oxygen from hot water in the Irene Kaufmann Settlement House in Pittsburgh, where considerable trouble had been experienced with rusty water due to corrosion of iron pipes. The principle employed is to fill a storage tank with suitably prepared steel lathing (26 B. W. G.), designed so as to pack closely with an exposed surface of approximately 100 sq. ft. per cu. ft. of space. In passing the water heated to 160 deg.

fahr. through this metal, all the oxygen is fixed in the form of hydroxides which are readily removed by filtration through a sand filter. The result is water inactive toward iron or other metals, free from oxygen but otherwise unaltered in composition except for the presence of a small amount of free hydrogen resulting from solution of iron in the "deactivating" tank. The results have been entirely up to expectations based on research work previously done, as the pipes carrying deactivated water have shown no measurable corrosion in four years service whereas before this system was installed, some of the pipes were perforated and nearly plugged up with rust in this time. The corrosion in the old piping had evidently been arrested as no further pit holes developed after the plant had been in operation a few weeks.

Another plant was installed in Boston in a 26 dwelling apartment house in March, 1917, to afford further study of this problem in practice under different water conditions. The design was somewhat different from the first plant described but the results have been equally satisfactory. Details as to the operations of these plants, which were comparatively small and necessarily more or less experimental, will be found in a paper on "The Preservation of Hot Water Supply Pipe in Theory and Practice," by Speller and Knowland, Transactions of AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, 1918.

THE INSTALLATION

The installation to be described was designed for a 12-story building containing 107 apartments of the best type, which was constructed in 1918 on the block between Park and Madison Avenues, 47th and 48th Streets, New York. This plant was designed to deactivate 6,000 gal. of water per hr. at a temperature of 160 deg. fahr. The size was over 10 times that of any previous plant which had been operated and presented some problems which could not be solved without experience on this scale. The piping arrangement and filters were laid out as shown in Fig. 1 so as to permit any combination desired for experimenting.

The water heating equipment is divided into two independent sections, supplying the East and West buildings. The arrangement is the same for both, therefore only the equipment for the West building is shown in detail. Fig. 2 indicates the main features of this plant in diagrammatical form. This consists of two steam heaters and storage tanks of the usual type, the outlets of which are connected with the top of a deactivating tank 15 ft. long and 5 ft. in diameter, filled through the manhole at one end with strips of steel lathing supported on cross bars 4 in. above the bottom of the tank. The water is drawn off at two places from the bottom of the deactivating tank and passed through ordinary sand filters arranged in parallel as shown. From these filters the water is passed through the system and is circulated by means of centrifugal pumps through return lines and a small booster heater to the filters and back to

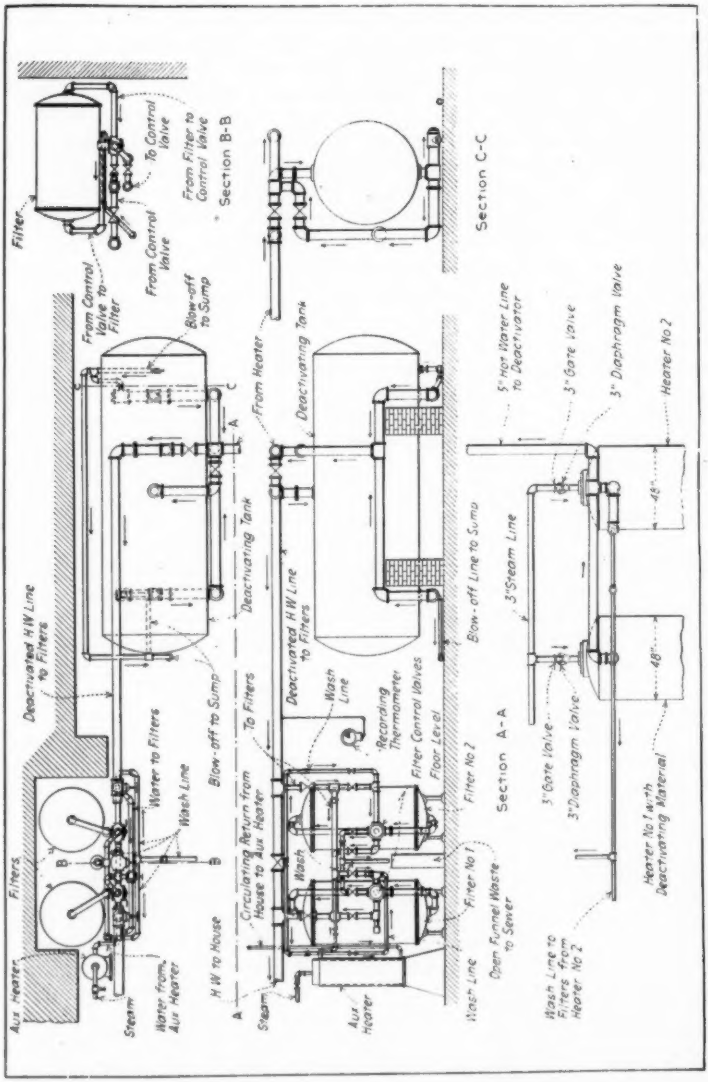


FIG. 1. ARRANGEMENT OF PIPING AND FILTERS IN DEACTIVATING PLANT OF 12-STORY APARTMENT BUILDING.

the system again. In this way only the make-up water is passed through the main heaters and deactivating tanks. One of the heaters has been filled with steel lathing above the heating coils Our experience with this arrangement indicates that with storage capacity slightly greater than that usually provided in such heaters, it is possible to heat and deactivate the water in one tank as shown but it is desirable in such cases to have two heaters to provide water when either one of these tanks requires cleaning out. Recording thermometers were provided at the heaters and in the main from the deactivator before the water enters the filters. In circulating the water through the building the temperature is reduced 25 to 30 deg. fahr. which is made up in the small booster heater. By this treatment, with a maximum flow of 5,000 gal. per hr. the free oxygen is reduced to less than 0.10 cc. per litre. In the previous installations described in Pittsburgh and Boston, the average oxygen content, in periods of maximum use of water, runs about 0.4 cu. cm. per litre without showing noticeable corrosion in nearly four years service.

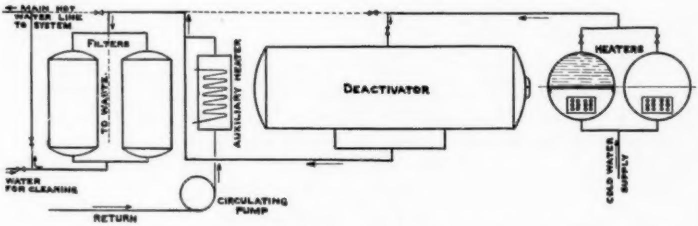


FIG. 2. DIAGRAM OF THE MAIN FEATURES OF DEACTIVATING PLANT.

While there may be other means for removing oxygen which will reduce corrosion to a minimum, such as heating the water nearly to the boiling point in a vented tank, the method described has the advantage and simplicity of being automatic in that only as much iron is taken up as is necessary to fix the free oxygen so that several years' supply of sheets may be kept in the storage and deactivating tank. Furthermore the water need not be heated above the temperature at which it is required for use and no attention is needed except for the regular periodic reversal of the filters which can be readily attended to without the aid of an engineer, so that, with the exception of the interest on initial cost of installations, the cost of treatment may be said to be very little more than the cost of renewing the deactivating sheets from time to time. No allowance is required for deterioration of tanks or filters, as there is no reason to anticipate any serious corrosion of these parts during the life of the building, and for the same reason this should be true of the heaters when filled with deactivating plates.

Galvanized steel pipe was used in the installations described. Without deactivation, the life of wrought-iron or steel under such

conditions in large hotels, apartments and similar buildings in New York City is often not over 7 or 8 years. Brass pipe will not show evidence of deterioration from this cause until a few years longer as the water is not discolored by the products of corrosion in this case. Brass pipe is, however, often seriously weakened and ultimately destroyed by dezinkification which is largely prevented by deactivation of the water. Our experiments with deactivated water in service indicate that the corrosion of zinc and brass is thereby greatly retarded as would be expected from experience with iron.

The author believes that the problem of preventing corrosion in feed water pipes, heaters and boilers, can be solved in a similar manner by removal of the free oxygen. Where the make-up water is comparatively pure, there is no doubt that reduction of the free oxygen to 0.10 cc. per litre will practically eliminate this trouble.

Economizers are particularly subject to rapid corrosion where the feed water is not deactivated and for this reason the heavy walled cast-iron tubes have been used for this purpose at a considerable sacrifice of safety and efficiency. The use of deactivated water makes possible the use of standard charcoal-iron or steel boiler tubes in economizers.

In these times, economy and conservation of material mean so much to the world that we feel no apology is necessary in calling the attention of enginners once more to a rather neglected branch of their profession—ANTI-CORROSION ENGINEERING.

DISCUSSION

THE AUTHOR (W. H. Walker): The importance of a study of the corrosion of iron, (I do not distinguish in discussing corrosion any difference between wrought iron and steel) is appreciated when one considers the enormous amount of iron which is in use throughout the world, and the total yearly loss which is occasioned by its inherent tendency to corrode or rust. Anti-corrosion engineering is, therefore, a broadly conservative subject and should enlist the attention of every thoughtful engineer.

While modern water supplies may contain as normal constituents, materials which somewhat accelerate the rusting of iron, these will be omitted from the discussion of this paper because we have this morning to do with that constituent which is altogether controlling in the rate with which an iron structure exposed to water deteriorates, namely, oxygen. It has been conclusively shown that iron in the absence of water will not rust and also, that iron in the presence of water but in the entire absence of oxygen will not rust. It has also been shown that the rate of corrosion is a direct function of the concentration of oxygen and the temperature; that is, water charged with atmospheric air will rust iron pipes more rapidly than water containing less air, and water at a high temperature, such as is used

in the hot water supply systems of modern dwellings, will cause iron pipes to rust more rapidly than the cold water supply from the street. Since it is imperative that fresh hot water be supplied to the consumer, the only remedy lies in the removal of the oxygen.

The present system provides for this by, first, heating the water in order that it may be as active as possible, and then allowing this active water to come in contact with a very large surface of such iron as corrodes very rapidly. In other words, the water is allowed to use up its oxygen on iron which is easily replaced and inexpensive to supply, instead of consuming the iron of the pipe system which is high as to first cost and very expensive to replace. The results so far obtained are most encouraging, and we firmly believe that there is here supplied a means by which the iron and brass piping of hot water supply systems can be indefinitely preserved.

James Aston (written): Oxygen is one of the several important factors promoting and accelerating the corrosion of iron and steel. The attack should diminish with its removal from the water. The value of any method to accomplish this end depends upon the effectiveness of the oxygen removal and the relative cost of the operation.

There are several points warranting careful consideration in the type of system described in the paper:

1. Removal of oxygen may not be uniformly obtained to the necessary degree for holding the corrosion in check, due to neglect or inefficient supervision, deterioration during service, inactivity at times of low water temperature, and introduction of oxygen when cleaning equipment and washing filters. While normal water supplies carry from 7 to 8 cc. of oxygen per liter, experience indicates that in hot water service the diminution of oxygen activity is very probably not obtained until the content is reduced to what may be called a critical limit of concentration of 1 to 2 cc. per liter. Consequently introduction of the full oxygen content of the water into the pipe system for comparatively short intervals, air leakage, or an apparently minor loss of efficiency of deoxidation, will be accompanied by serious corrosion.
2. Deactivation with respect to oxygen is not the whole story. Other gases and other factors are at work in no small degree. Broad generalities with regard to the necessity of oxygen for depolarization of the hydrogen liberated during solution of iron, must be greatly modified in considering pipe service. Mechanical depolarization, especially with the rapid flow prevailing in hot water supply systems, may be extremely effective in the average systems now in use.
3. The system described involves an initial investment and yearly operating and upkeep charges of no inconsiderable amount. For 6,000 gal. per hour of steady flow of water, effective deoxida-

> tion would necessitate wastage of over 10 tons of metallic lath and the production of 10 tons of rust annually, based upon discarding the deactivating material when 50 per cent converted to rust, which is all that would be safe without danger of losing deactivating efficiency. Actual results for the installation in question will depend upon the ratio of average consumption of water to the 6,000 gal. per hour of rated capacity of deactivation. This would seem conservatively to be at least one-tenth of the above amounts.

The life of hot water service pipes is stated in the paper to be 7 or 8 years in New York City. This conforms fairly closely with our own data on steel pipe obtained in a very extensive investigation of hot water service in hotels and apartment buildings in that city. Wrought iron is not in this category, however, whatever the paper may intimate in this regard; double the life of steel is a conservative figure based upon history of actual service.

Anti-corrosion engineering is an important branch of the engineering profession, and has been too much neglected. There are two prominent methods of attacking the problem. One involves the elimination of oxygen or like factors. The application is entirely specialized and adapted only to particular classes of service, and then only with an uncertain, and as yet, undetermined result. The second method, is by proving greater or entire immunity to the corrosive attack. For general service, and for pipes in particular, wrought iron has demonstrated its superiority over steel. Unfortunately, vigorous propaganda, a "just-as-good" or "take-a-chance" policy, and a desire for cheapness, led to steel installations. These have been accentuating attention to the corrosion problem because of the relatively rapid deterioration. The conservative ones who have clung to wrought iron or brass, have had no reason for regret. The radical has paid, or is paying the penalty for his false economy. The inevitable result is a very noticeable and very healthy reaction in favor of wrought iron pipe for buildings of a permanent character.

Reverting to the subject of the deactivating equipment, we will now admit, for the sake of the argument, that it will do everything claimed for it in the paper. It would be absurd, however, to claim that it would not be as beneficial to a wrought iron pipe system as to a steel pipe system, even though admittedly the necessity for installing such a costly apparatus is greatly minimized by the use of the more rust-resisting pipe material. We believe, however, that there will be no disputing the fact that in all but the most rare and exceptional cases, a straight brass installation will not only do away with the necessity for the deactivating equipment, but be more desirable because of saving the space occupied by the extra equipment and the absence of maintenance charges therefor. The practicability of the apparatus advocated may, therefore, be decided by a compari-

son of initial cost; even if this cost should be a trifle higher for brass pipe the latter would still be preferable for the reasons just stated. It would be of interest further to know how the cost of the deactivated steel pipe system compares with the cost of a non-deactivated wrought iron pipe system using either standard weight or extra heavy galvanized pipe. The following rough estimates based on an installation in a building such as described in the paper under discussion, indicates that the equipment is far too expensive to be of practical value.

HOT WATER SUPPLY SYSTEM IN 13-STORY APARTMENT BUILDING, 100 BATHS

1. GALV. WROUGHT IRON (Std. Weight).	
Pipe (W. I. with brass for horizontal runs to fixtures)	$1,356.00
Valves and Fittings	1,612.00
Labor (shop cost and erection)	2,420.00
Miscellaneous (including overhead, profit, supervision, etc)	1,942.00
Total	$7,330.00
2. ETXRA HEAVY GALV. WROUGHT IRON.	
Pipe (W. I. with brass for horizontal runs to fixtures)	1,687.00
Valves and Fittings	1,812.00
Labor (shop cost and erection)	2,530.00
Miscellaneous (including overhead, profit, supervision, etc.)	1,993.00
Total	$8,022.00
3. GALVANIZED STEEL PIPE WITH DEACTIVATOR.	
Pipe (Steel with brass for horizontal runs to fixtures)	1,206.00
Valves and Fittings	1,612.00
Labor (Shop cost and erection)	2,420.00
Miscellaneous (including overhead, profit, supervision, etc.)	1,924.00
	$7,162.00
Two deactivators and four filters installed	16,000.00
Maintenance: $300 yearly, which equals 6% on	5,000.00
Total	$28,162.00
4. ALL BRASS PIPE.	
Pipe	$3,137.00
Valves and Fittings	1,612.00
Labor (shop work and erection)	2,660.00
Miscellaneous (including overhead, supervision and profit)	2,224.00
	$10,433.00

Note: These estimates include only the hot water supply pipes with incidental cost of installation such as valves, fittings, labor, and other items which form an integral part of the system, but not including fixtures.

It would appear from these figures that one could install brass pipe and fittings throughout for this system, at a total initial cost of $10,433, which is about one-third of the sum representing the initial investment in the steel pipe system including the investment of the sum of $5,000 to take care of maintenance charges for the deactivators. The $300 set aside for this purpose include the cost of removing the corroded sheets and installing new ones in their place. Even the installation of extra heavy galvanized genuine wrought-iron pipe, with brass pipe used under the bath-room and kitchen floors, cost only one-quarter as much as the system advocated in the paper, yet the former would give almost indefinite life under conditions such as exist in New York City, the only items of replace-

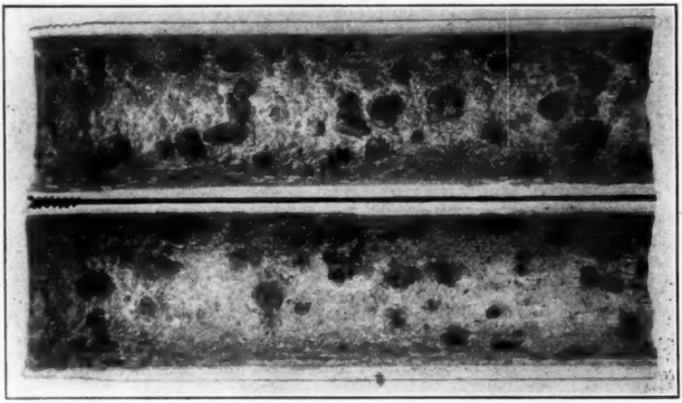


FIG. 3. GALVANIZED WROUGHT-IRON PIPE FROM LINE CARRYING UNTREATED HOT WATER, IN USE TWO YEARS.

ment being the exposed wrought iron basement mains; even these, from service records collected in over 100 large New York apartment buildings, would appear to have a prospective life of from 20 to 30 years if extra heavy wrought iron pipe is used. The risers in comparison would probably have a life of 60 years or more, being subject to very much less corrosion than the mains.

While there appear to be some very good reasons, not connected with the question of internal corrosion, why the horizontal piping under bath-room and kitchen floors should be brass, we will now assume for the sake of the argument that it would be safe to use galvanized steel pipe in these places in the system protected by the deactivating apparatus. Further, having no data upon which to base our estimate of the cost of the deactivators and filters excepting the drawings accompanying the paper under discussion, we will assume that the cost of this equipment could be reduced by one-half, namely, from the $16,000 estimated, to only $8,000. The cost of the steel pipe installation would then be as follows:

STEEL PIPE HOT WATER SUPPLY SYSTEM WITH DEACTIVATORS AND FILTERS

1.	Pipe, steel throughout	$ 428.00
2.	Valves and fittings	1,612.00
3.	Labor (Shop work and erection)	2,420.00
4.	Deactivators and Filters, installed	8,000.00
5.	Overhead, supervision, profit and miscellaneous	1,942.00
		$14,402.00
	Maintenance: $300 per year, which equals 6% on an investment of	5,000.00
	Total	$19,402.00

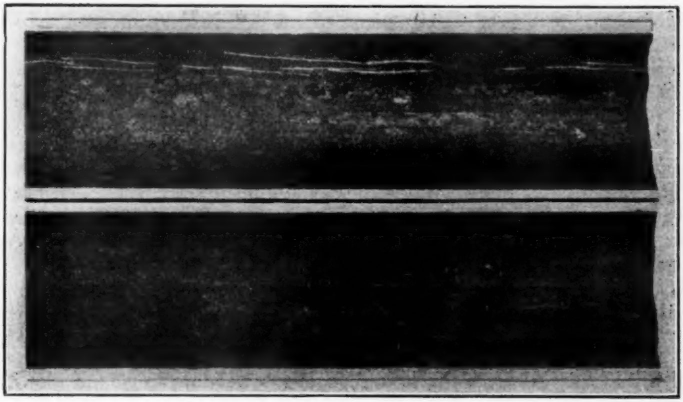


FIG. 4. BLACK STEEL PIPE FROM LINE CARRYING DEACTIVATED HOT WATER, IN USE OVER THREE YEARS.

Even though this estimate appears to be entirely too low, it will be seen that the investment is nearly twice as high as for a standard brass pipe installation and about two and one-half times greater than the investment in a genuine wrought iron pipe installation. From a standpoint of practical utility, it is of the utmost importance that accurate installation figures for the system advocated in Mr. Speller's paper be considered. In compiling such figures, however it should be distinctly borne in mind that the piping cost should be solely for the hot water supply system, not including fixtures nor any other items which go into the ordinary plumbing estimate, such as cold water supply, drainage and vents, fire lines, etc. The deactivator can only protect the hot water supply piping.

G. B. Nichols: This is one of the most important subjects confronting the domestic hot water service today. I dislike, however,

to see this discussion driven into one between wrought iron, steel and brass pipe, as it is a very much broader subject than this.

The use of brass pipe in no way solves the problem, as brass pipe is attacked to a great extent by certain active waters. I believe that Mr. Speller is proceeding along the right line in trying to deactivate the water, although I believe that there are other agents besides oxygen, which play an important part in the corrosive action of various active waters. On a recent visit to the Massachusetts Institute of Technology, I was surprised to see the amount of lead lined pipe installed to avoid the corrosive action of the water, and I believe that the subject of deactivating water should be undertaken by this Institute and reported upon definitely.

THE AUTHOR (F. N. Speller): Mr. Nichols asks as to whether deactivation will prevent corrosion of brass. In my notes on deoxidation of water at the Annual Meeting of this Society in 1919, there were given in Table 2 some tests of brass, zinc and copper in untreated and deactivated water, which show the same reduction in corrosion as in the case of iron pipe. The white salt which forms on brass pipe is due to the dissolving out of the zinc and the deposition of carbonate of zinc. This continues until the pipe consists only of porous copper. Many cases have been seen where the brass pipe was affected in this way; this does no particular harm unless the pipe is subject to strain of some kind, when it is liable to fracture easily.

The commercial side of water deactivation is now receiving considerable attention. Mr. Aston's calculations of cost are purely hypothetical. The cost of the installation described in our paper was such that the owner of the building did not hesitate to go ahead with the work and later on had several similar plants put in other buildings which he controls. No doubt with more experience and standardization of apparatus the cost will be reduced but at present it is well within the difference in cost between brass and steel pipe.

The cost of iron sheets consumed is about 1½ ct. per 1,000 gal. of water based on steel sheets at 5 ct. per lb., but what is this compared with the expense of renewing the same amount of iron in the piping system every seven or eight years at a cost of at least 10 times the value of the pipe for such renewals. Several service tests reported in the Transactions of this Society, answer the question raised by Mr. Aston as to the relative durability of these metals. Extra strong wrought iron has been tried out in New York buildings, but the extra heavy wall seems to cause the formation of more rust so that the pipes plug up more tightly. Some double extra strong hot water wrought iron lines in the Hudson Terminal Building were completely closed on this account during the past year.

With reference to the practical operation of deactivation I submit a letter, written to Mr. Sidney A. Teller, Director of the Irene Kauf-

mann Settlement, by James O. Handy, Technical Director of the Pittsburgh Testing Laboratory.

Mr. Sidney A. Teller, Pittsburgh, Pa., Jan. 22, 1920.
Resident Director, Irene Kaufmann Settlement,
1835 Center Ave., Pittsburgh, Pa.

Dear Sir:

Complying with your request of December 30th, I have inspected the galvanized wrought iron and steel pipes which were installed at the Irene Kaufmann Settlement in the line which carries untreated water, after heating by means of automatic water heaters.

The line referred to passes through the boiler room on its way to the bath rooms above. It consists of approximately 30 in. lengths of commercial galvanized wrought iron and steel pipes. The iron pipes were lap-welded and the steel pipes buttwelded. The order of arrangement of the pipes in the line was, steel first, then iron, then steel, then iron, and the same order was continued to the end. In this way the first steel pipe was subjected to the most active corroding influence, but the arrangement as a whole gave almost equal exposure to both iron and steel.

The installation was made on December 24, 1917 (two years and seven days prior to the date of inspection and removal). There were four sections of wrought iron pipe and three sections of steel pipe of the same length, and one short section of steel pipe, approximately 10 in. long. All of these except one very short section of steel pipe had corroded through at the thread. No differences were observed between the wrought iron and the steel pipes before cleaning. They all showed large tubercles of rust, covering most of the inner surface, and having a thickness of about ¼ in. After cleaning it was found that deep and large pits were very general in both iron and steel pipes. In all cases the zinc coating had practically disappeared from all parts of the surface. Deep pits were present at the points where the zinc had first disappeared.

The grading of the corroded pipe was carried out by measuring the depth of about 30 pits which seemed the deepest, and of those the deepest pit was taken as the measure of corrosion in each case. By this method of grading, carried out by two independent observers, the results were as follows:

	Deepest Pit
Steel No. 29	0.1345 in.
Wrought iron No. 4	0.1205 in.
Wrought iron No. 19	0.1190 in.
Wrought iron No. 7	0.1175 in.
Steel No. 6	0.1030 in.
Steel No. 9	0.1030 in.
Wrought iron No. 5	0.1005 in.
Steel No. 8	0.0975 in.

	Average of Deepest Pits
In steels	0.1095 in.
In wrought irons	0.1144 in.

These figures show that no marked distinction is possible between the rate of corrosion of the steel and the iron pipe. Steel and iron are found side by side at both ends of the list.

Comparing the durability of uncoated steel pipe and uncoated wrought iron pipe, when used for conveying to your laundry and residence hot water which has passed through the Speller Deactivator, I find that after 3 years and 39 days of such service, there has been no recognizable corrosion of either kind of pipe. There were three pits in the wrought

iron pipe, but it is believed that these represented blisters or unfilled cavities which were originally present.

The efficiency of the Speller Deactivator is remarkable. It has continuously removed the dissolved oxygen from the water, and made it possible to use indefinitely uncoated iron or steel pipe.

The only difference between the hot water which corroded through galvanized pipe in two years, and the hot water which had no corroding effect upon uncoated iron or steel pipe in three years, was the presence of the normal amount of dissolved oxygen in the first case, and its absence in the last.

* * * * * * * *

Yours very truly,
PITTSBURGH TESTING LABORATORY,
(Signed) Jas. O. Handy,
Technical Director.

PERRY WEST: With regard to the cost of the water deactivating apparatus, we have been doing a great deal of estimating and we find, in regard to the cost of this apparatus, that it will run somewhere between 2½ and 4 per cent of the cost of plumbing in a building; the cost of brass pipe at the present day, over the cost of either steel or wrought iron, is in the neighborhood of 1000 per cent; also the cost of operation of the plant is practically nothing. The operating cost really simmers down to the water required to wash the filters, because the force that takes care of the hot water plant can just as well take care of the deactivating plant. There is nothing to do except to wash the filters about once a week.

ALFRED TJERSLAND: Twenty or twenty-five years ago we had not this condition of today arising from electrical action on the pipe. When you put in big piping in a building there will always be some leaks. Through the reinforced floors a light iron is used and some electrical current goes through this iron and perhaps enters the piping and rusts it. In Europe we could not understand why much of the brass, wrought-iron, and steel pipe was corroded in a short time; we took out some pieces which had been eaten up in a few months to replace them with copper piping and we saw also to a certain degree the electrolytic action which had come from the electric lighting lines. In research work, and especially when seeking data for the life of piping under different conditions, we must always reckon with the electrolytic action on the piping. I do not know if it is the custom in this country, but in our country all the telephones are connected to the cold water main. We do not use lead pipe; we use iron and steel pipe. We have seen that the surfaces of the pipe between the main and the house connection have been eaten up with electrolytic action, and we have also seen that gas pipe in the street, through the action of cables in the ground, has been eaten up in the same way.

E. S. HALLETT: I am interested in the corrosion of return pipe in our steam heating systems. Where the condensation from the vento

coils is returned, we have corrosion in the pipes. We have been able to take care of the pitting in the boilers through electrolytic means, but have no means so far of correcting the pipe deterioration. Now in a case of that kind I wonder if it is necessary to put this filter in: I did experiment by using sheet iron punchings in the open heater and it seems certainly to have corrected the visible effect, as we observed it in the boiler. Is it necessary in a case of that kind to put the filter in? Could not the iron oxide be returned to the boiler and be cleaned out with the other material that accumulates in the boiler?

S. J. BROWN: Mr. Speller spoke of the increase in the pressure in this test he made on the corrosion. I would like to know whether he accounts for that increase in pressure by the decrease of friction

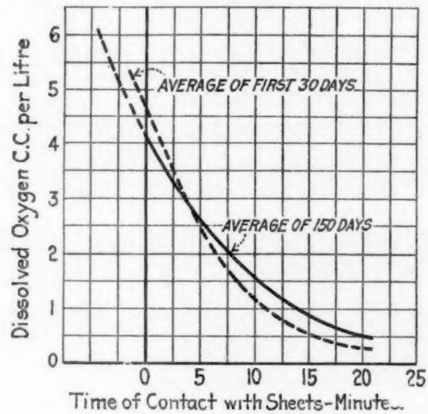


FIG. 5. CHART SHOWING PROGRESSIVE REDUCTION IN FREE OXYGEN IN WATER AT 160 DEG. FAHR., WITH CONSTANT FLOW AND VARIOUS PERIODS OF CONTACT.

Steel sheets packed so as to have 100 sq. ft. of surface per cubic foot of space.

in the pipe, occasioned by the removal of these particles of corrosion of which he speaks. If so, would it not result in economy in the heating and circulating of the water through those pipes?

THOS. BARWICK: I would like to ask Mr. Speller if he has made any experiments in the operation of salt water systems with an electrical line running adjoining to it; that is, to find whether the discharges from the electrical line into the water that passes through the pipes has any effect beyond the oxidization that comes from the oxygen in the water.

I would also like to know what he has done in the matter of the insertion of iron pipe, wrought iron or steel, in cinder concrete. We find a great many buildings built of cinder concrete at thepresent

time, in which their pipes are inserted under the floor, and a great many of them have given out from electrolytic action.

THE AUTHOR (W. H. Walker): Replying to Mr. Brown's question regarding the increase in pressure at the top of the apartment house in which the deactivator was installed, would say that the house is divided into two large wings, identical in every respect.

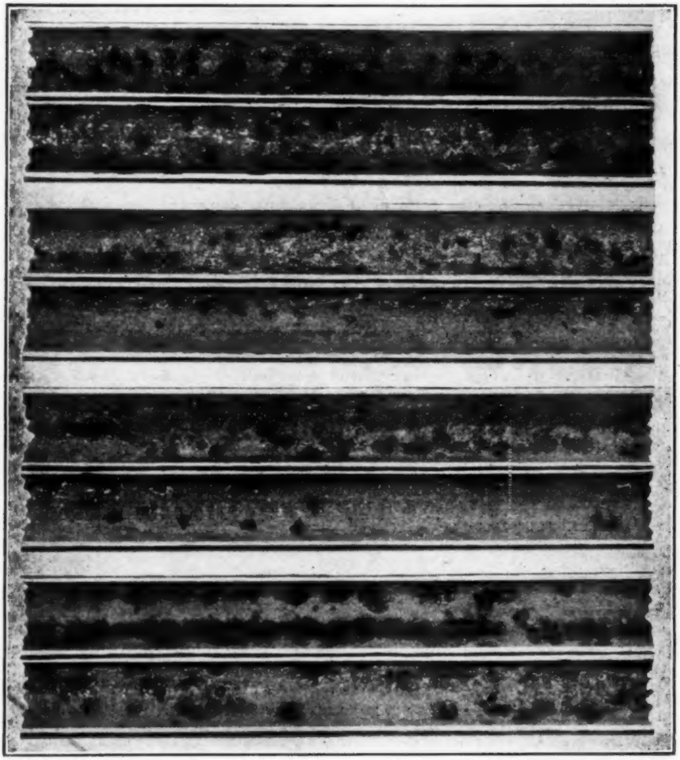


FIG. 6. GALVANIZED WROUGHT IRON PIPES FROM LINE CARRYING UNTREATED HOT WATER, IN SERVICE TWO YEARS.

Each wing has its own independent hot water supply system. Both of these wings had been in operation some years and the pipes were badly clogged, showing a very marked drop in pressure on the top floor. After the deactivator was installed, notwithstanding the fact that the filter was operating successfully, rusty water would periodically appear. This, however, in six months or so disappeared. The pressure on the top floor slowly and continuously increased in this wing and our explanation is that, owing to the absence of further

corrosion, the rust which had accumulated in the pipes would, at periods of high velocity, be dislodged and carried away. This is the only explanation which I have, because, of course, the iron rust already accumulated is not in itself soluble. As the cross section of the pipe is thus increased, the flow is also increased, and the pressure brought back to is normal value.

S. J. BROWN: If that were so, would it be more economical to heat that side of the building with that friction removed?

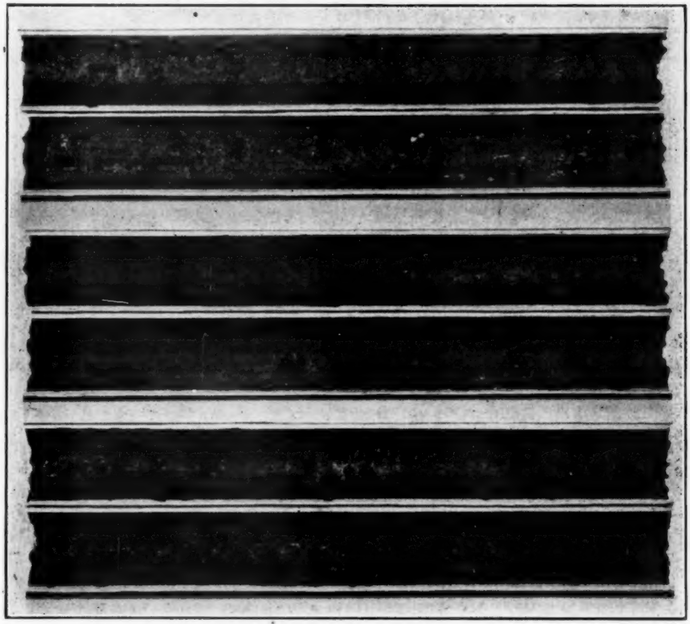


FIG. 7. GALVANIZED STEEL PIPE FROM LINE CARRYING UNTREATED HOT WATER, IN SERVICE TWO YEARS.

THE AUTHOR (W. H. Walker): I do not think it is more economical because the tenants use the same quantity if not more water, and the absence of complaints from the people at the top of the house is of sufficient value to add to the economy of the process.

THE AUTHOR: (Mr. Speller): In regard to the question of the necessity for filters in power plants and return heating lines using deactivated water, I can say that it is not necessary to use filters where a little color in the water is not objectionable. Most of the rust stays in the deactivating tank but the water, when deactivated in this way, has a rusty color which must be removed by filtration when

the water is used for domestic purposes. The Duquesne Light Company of Pittsburgh, Pa., in connection with one of their power plants installed a deactivator of this kind without a filter to take out the residual oxygen from their feed water and have had no trouble with the boilers. In fact, the boilers have been operating with cleaner water than they had before, because the sheets retain much of the sediment.

Stray electric currents have no effect on internal corrosion; these act entirely on the outside of the pipe. We get electrolysis, of course,

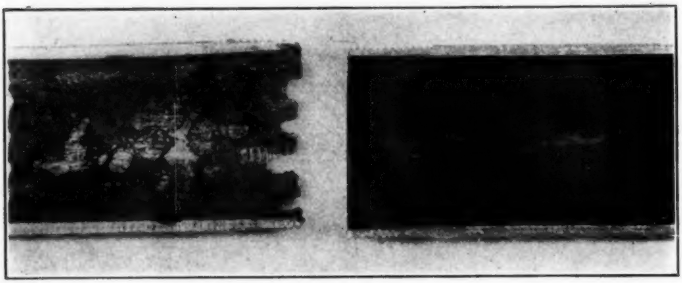


FIG. 8. COMPARISON BETWEEN WROUGHT IRON PIPE CARRYING UNTREATED WATER AND THAT CARRYING DEACTIVATED WATER. AFTER THREE YEARS OF SERVICE.

only when the current leaves the pipe. The electric current will not go into the water as a rule, because the wall of the pipe is usually a better conductor than water.

As to the effect of cinder concrete on pipe, that is getting a little away from the subject. The effect of cinder is usually to create an acid condition surrounding the pipe which corrodes the outside of the pipe. One way to correct this condition is to use some lime mortar around the pipe so as to neutralize the acidity. If cinders must be used the better way is to keep these cinders away from the pipe, using a substantial protective coating, or to neutralize the acidity of the concrete by intermixing a small amount of lime. Probably it would be better to use both these protective measures.

No. 555

TEST OF THE BEERY SYSTEM OF HEATING AND VENTILATING

BY CLINTON E. BEERY, CHICAGO, ILL.

Member

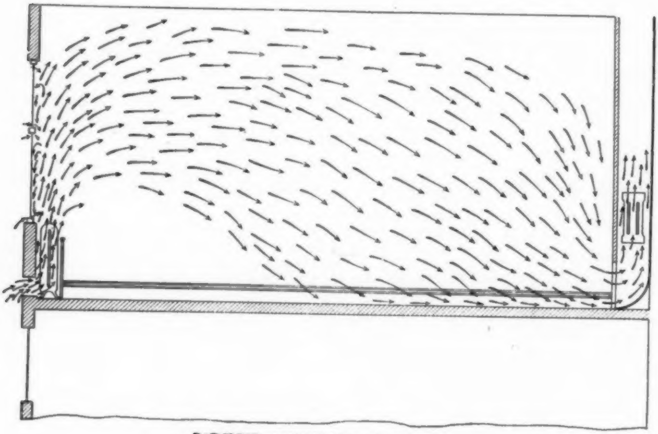
THE purpose of this paper is to describe the results of a test of the Beery system of heating and ventilation as installed in the Lincoln school at Rockford, Ill., which was made on February 2nd, 1917. The features which were given the most attention in this test, and which will be described are, *first,* the heating effect of the system, and *second,* the distribution of the ventilation.

The purpose of any well designed system of heating and ventilation is, first, to furnish sufficient capacity of heating surface or radiation to heat the building to a comfortable temperature in a reasonable space of time; second, to distribute that heating surface in a manner that all occupied portions of the building will be uniformly and evenly heated; third, to provide fresh air for ventilation to supplant all air that has been used for breathing or polluted with excretions from the body.

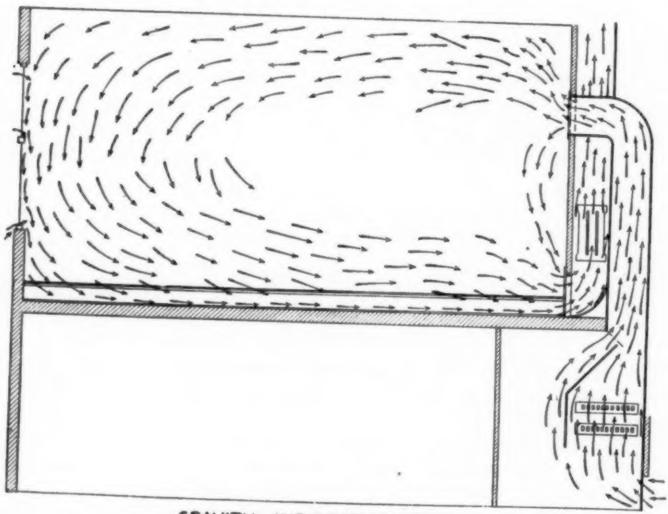
The field of school house heating might be divided into four general classes, in each of which an attempt is made to ventilate as well as to heat the class room. Each of the systems mentioned in the following paragraphs has merits. They have been designed, installed, and tolerated by reasonable people. The systems are listed in the order of their historical development.

First, the so-called *Direct-Indirect Heating System.* In this system direct radiation is distributed as in the ordinary direct heating system. A sufficient extra amount of radiation is provided to heat the fresh air necessary for ventilation. Certain of the radiators are provided with "wall boxes" and a shield in front of the radiator to prevent draughts (see Fig. 1). Air is continually drawn up through the radiator from the outside, heated, and thrown out into the room, and in Hoffman's Handbook on Heating and Ventilation it is stated: "Thus is established a ventilating system more or less effective." The air is vented from the room through a vent duct which usually

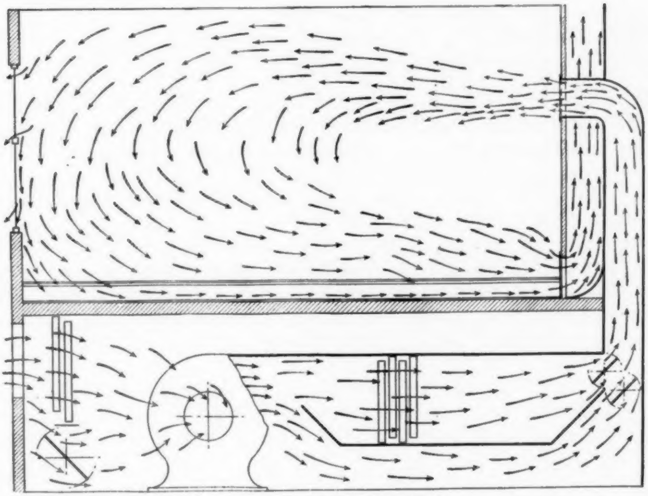
Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, January, 1920.



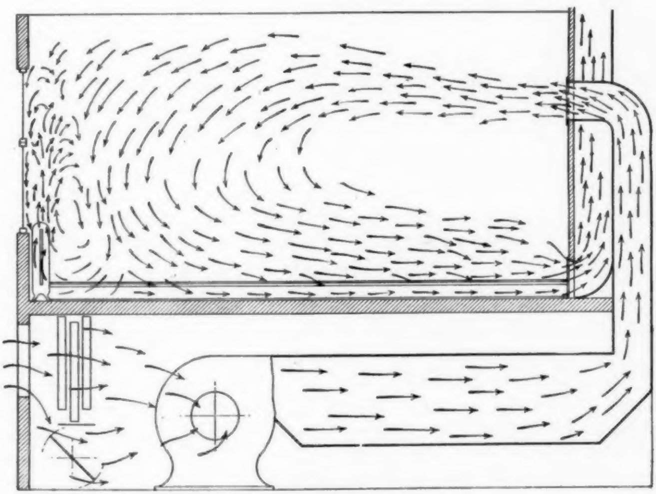
DIRECT-INDIRECT SYSTEM
FIG. 1



GRAVITY-INDIRECT SYSTEM
FIG. 2



PLENUM SYSTEM
FIG. 3



SPLIT SYSTEM
FIG. 4

has its opening at the floor line. The movement of the air through this duct is generally accelerated by means of an aspirating radiator.

The merit of the direct-indirect system is said to lie in the *absence* of mechanical apparatus which requires skilful care.

Its main faults are first, the ineffective distribution of the fresh air for ventilation, and second, the ease with which the occupants of the room can destroy the effectiveness of the system.

Second: *The Gravity Indirect System.* In this system the heating surface is concentrated in certain basement rooms and separate ducts carry the heated air by convection to the rooms to be heated (see Fig. 2). Aspirating radiators are provided in the vent ducts to further accelerate the movement of the air. This system has generally the same merits and faults as the direct-indirect system, its main fault being the difficulty of control.

Third: *The Plenum or Blast System.* This system is similar to the second but uses a fan or blower to force the air to the various rooms, through and out through the vent ducts. Aspirating radiators are not used (see Fig. 3).

This system has possibly gained the greatest favor in the past through its qualities of furnishing positive heating and ventilation from the same source, and lending itself readily to control. In order to heat the rooms in cold weather, it is necessary to heat a portion of the air to rather high temperatures, which, it is claimed, vitiate the air. With this system it is oftentimes difficult to heat rooms exposed to severe wind and cold. It is also necessary to run the fan through long hours in severe weather to keep the building warm.

Fourth: *The "Split System" or The Direct and Indirect System.* In this system direct radiation distributed throughout the building is provided to supply the heat loss from the building, while the fan system is provided to distribute air for ventilation (see Fig. 4).

The great merit of this system lies in the fact that the largest building may be kept heated continuously, while the ventilation need be used only when the building is occupied. Both the sources of heating and of ventilation may be readily controlled as to temperature. The air is never raised to a point where it is vitiated. The main fault with this system as well as with the preceding one is the difficulty of properly distributing the fresh air for ventilation. The mechanical or fan systems mentioned above depend mainly on the velocity at which the air is introduced for the effectiveness of its distribution, the ventilation being obtained by the so-called "dilution process."

Generally speaking the Beery system would fall under the last heading. Its novelty lies in the following details:

a. That the ventilation or fan system is a complete plenum system in which the maximum difference in temperatures between the "warm" and "tempered" air is but 10 deg. fahr., while the temperatures carried are respectively 75 and 65 deg. fahr.

b. That the "radiation" to supply the heat loss from the room consists of two coils of 1¼ in. pipe running completely around the room above the picture moulding line.

c. That the air for ventilation is introduced through diffusers a few inches below the ceiling line in the center of the room or, in large rooms, at central points in the room.

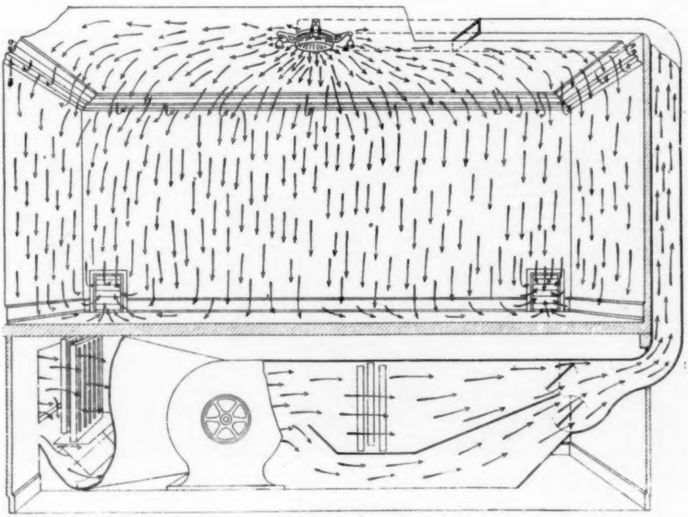


FIG. 5

TYPICAL APPLICATION OF THE BEERY SYSTEM TO A SCHOOLROOM.

d. That the air is vented from four outlets at the floor line generally located at the four corners of the room.

The various features of the Beery system are shown in Fig. 5.

The purpose of this test was to determine the details of operation of this system as compared with other commonly known systems of heating and ventilation. Detailed observation were made of the following items:

1. Distribution of air: i. e.; air currents in the room.
2. Canvass of the temperatures in the class room.
3. Record of the time and temperatures outside and in the various portions of the building.

The Lincoln school was one of the older school buildings, which, a short time prior to this test, had been thoroughly remodeled. In

fact nothing of the original structure had been used except the exterior walls. The building has solidly constructed brick walls and is provided with fireproof stairs and corridors. It consists of a basement, two stories, and a high attic. The window construction consists of wood frame with ordinary tight sash. The boiler room is separate from the main building.

The basement contains the manual training and household arts departments, a large play room and the fan room. These rooms, with the exception of the fan room and the play room, are heated with direct radiation, hung from the ceiling. The first floor contains four large class rooms, one recitation room, a library, and a

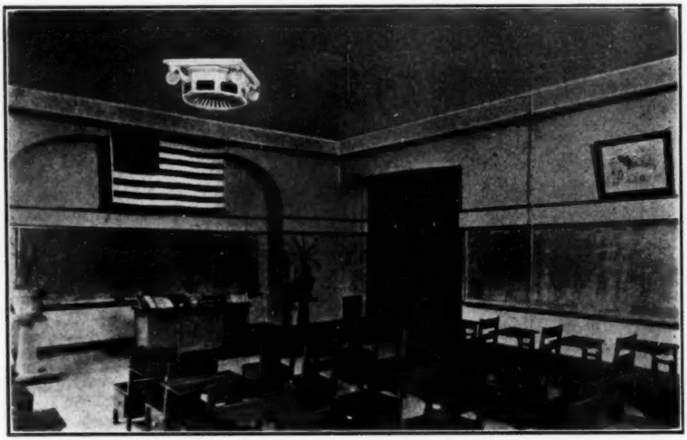


FIG. 6. ROOM IN LINCOLN SCHOOL, ROCKFORD, ILL., EQUIPPED WITH BEERY SYSTEM.

spacious corridor. The corridor and entrance are heated with direct radiation. The second floor contains six recitation rooms, a laboratory, a study hall, the principal's office, and two small toilets. The office and toilets are heated with direct radiation. The attic is large and well lighted, the roof being of the high gable pattern. It contains two finished rooms heated by direct radiation.

All vent ducts terminate in the attic in elbows which are provided with screened faces and with weighed canvass flaps which maintain a positive pressure in the rooms and prevent back draughts.

The mechanical equipment consists of one Kewanee downdraft boiler rated at 14,000 sq. ft. of radiation and designed for 100 lb. working pressure. The system of steam circulation is of the mechanical vacuum type, using MacAlear thermostatic traps. An American-Marsh steam pump maintains the vacuum on the system while the boiler is fed by a pump of this same manufacture. Ven-

tilation is supplied to the rooms by a Sirocco fan rated at 20,000 cu.ft. of air per minute. This fan is driven by a 10 h. p., 220 volt, 3 phase, 60 cycle motor, that operates at 1145 r. p. m.

The air is passed through an air washer of the American Blower Co.'s mist type, which has an area of 50 sq. ft. The mist nozzles are supplied by a centrifugal pump driven by a 5 h. p. motor. The control of the humidity was accomplished by changing the temperature of the washer water. A three-way diaphragm valve was furnished to mix the hot and cold water supply to the pump. The water was heated by an Alberger heater.

The temperature of the plenum chambers, air washer and class

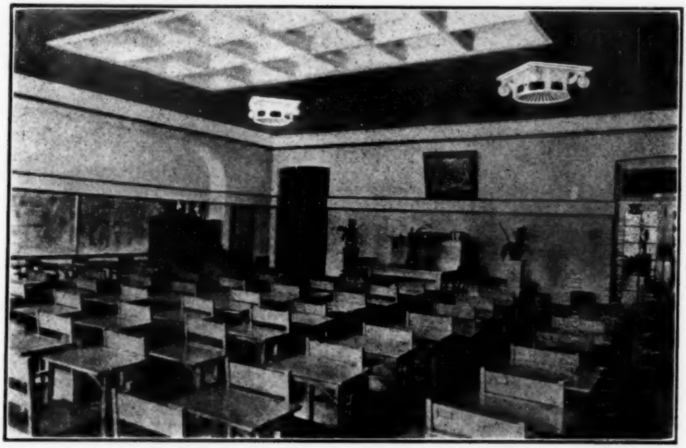


FIG. 7. STUDY HALL, LINCOLN SCHOOL, WITH 2¼ IN. PIPE COIL BEHIND CORNICE.

rooms is controlled by the Johnson system of heat regulation, which operates the valves on the vento sections to maintain the following temperatures: air washer 40 deg.; tempered air, 65 deg.; warm air, 75 deg., fahr. The rooms are maintained at 68 deg. Each room is provided with a graduated-acting room thermostat controlling a specially-constructed Beery mixing damper. An additional room thermostat is provided to control the pipe coils at the ceiling. This thermostat automatically closes up this coil after the other thermostat has operated the mixing damper to a position to pass tempered air only. The attic vent dampers are controlled from pneumatic switches in the basement. Means are provided to recirculate the air in the building so that the building may be heated rapidly in the morning.

Record was kept of all temperatures, weights and events that might have bearing on the operation of the system. All condensate

was weighed as it was returned from the coils and the radiation in the manner shown in Fig. 8. Two barrels were provided with valved openings in the bottoms, which were set on scales and arranged so that one barrel could fill while the other emptied.

Temperatures were taken at half-hour intervals at the following locations; outside the building; in each chamber of the fan system; in each room; in the condensate; in the make-up water. Record was kept of the boiler pressure and also of the reduced pressure to the heating system.

The above mentioned data were arranged in tabular form (see Fig. 9) as well as in graphical form. The accompanying curve sheets show graphical results of the temperature as well as the steam consumption data, in relation to the time, and also show the

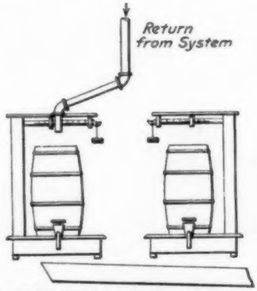


FIG. 8. APPARATUS FOR WEIGHING CONDENSATE RETURNED FROM COILS AND RADIATORS.

events during the day which might have an effect on the operation of the system.

Outside Temperature: Upon reference to the curve sheet it will be found that this dropped from 10 deg. at 6:30 A. M., to 8 deg. at 8:30 A. M., from which it slowly rises to 15 deg. at 1 P. M., where it remains until the close of the test. In addition to this rather low temperature, the wind was blowing at a 25-mile-an-hour rate.

Inside Temperature: It will be noted that the temperature rose very rapidly upon circulation of steam through the *room heating coils*. In fact with these coils only, between the hours of 6:30 and 7:30 A. M., the average temperature of the building rose from 47 to 63 deg. The fan was started at 7:30 A. M. and the air was recirculated in the building, which raised the temperature to 68 deg. in about half an hour. Reference to the temperature records will show that some of the rooms were overheated while others were not up to temperature. The temperature control system which was started at 7:30 A. M., closed off the heat sources to those rooms that were up to their temperature, and thus conserved the heat for cool rooms, but, since the ventilation air was still being recirculated, the over-

heated rooms did not receive immediate relief. At 8:30 A. M. the rooms, with but few exceptions were heated up to or slightly beyond 68 deg.

At this time fresh air was turned into the fan and the recirculation doors closed. It will be noted that the temperature average dropped slightly at this time. This might be explained in two ways: *first,* that the doors were opened to admit the children; and *second,* that the overheated rooms dropped to their normal temperature. The average temperature rises very slowly until at 11:30, when it is 68 deg.; here it remained constant until the fan was stopped.

TIME	A.M. 6:00	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	M. 12:00	12:30	1:00	1:30	2:00	2:30	3:00	3:30	4:00	4:30	P.M. 5:00
PLACE											TEMPERATURE											
MANUAL TRG.	50	50	56	60	64	64	64	63	62	64	64	64	65	64	65	65	64	65	65	64	64	62
DOMESTIC SC.	40	56	62	64	62	62	62	61	60	62	62	63	62	62	62	62	62	62	63	60	59	57
ROOM #1	54	60	70	73	74	69	70	71	69	70	70	70	70	69	69	70	69	69	68	69	68	66
#2	44	54	65	72	72	70	72	73	72	74	72	71	70	70	70	70	70	69	69	68	68	64
#3	48	53	62	68	72	69	70	70	69	69	68	69	69	69	69	69	69	69	68	66	65	68
#4	42	48	60	64	67	65	66	67	67	68	69	69	68	68	69	69	69	69	68	66	64	63
#5	43	48	60	65	70	66	68	68	67	68	70	68	68	68	70	70	70	70	69	68	65	63
LIBRARY					70	68	69	68	66	69	69	68	68	68	68	68	68	68	69	66	65	63
OFFICE	49	58	62	67	69	68	70	63	68	70	71	72	71	70	70	70	70	71	70	70	66	64
ROOM #6	56	56	67	74	70	68	68	68	69	71	71	70	68	69	68	69	68	69	68	69	68	67
#7	63	64	72	75	74	69	70	70	69	72	72	71	71	70	70	68	68	70	69	70	68	67
#8	44	46	52	56	66	68	70	71	69	72	71	70	69	68	68	68	68	68	68	67	65	64
#9	51	60	67	72	70	68	69	68	69	70	70	69	68	69	69	70	70	68	68	69	68	67
#10	50	62	71	76	70	69	70	70	70	70	70	70	70	70	71	71	71	72	71	70	70	69
#11	42	50	60	64	68	65	65	68	68	68	68	69	68	68	69	68	68	68	68	67	66	64
#12	47	68	67	72	69	68	68	68	67	68	70	70	70	70	70	68	68	70	70	68	65	64
#13		58	68	72	70	70	71	71	70	73	72	71	69	70	71	71	68	70	69	67	65	58
OUTSIDE	10	10	8	8	8	8	9	10	10	12	13	15	14	14	14	14	14	14	10	8	7	5
AIR WASHER	55	97	98	80	62	62	62	62	60	60	69	63	64	65	62	69	71	62				
TEMPERED AIR	93	86	100	76	63	64	63	66	66	66	67	63	64	63	64	64	64	66				
WARM AIR	111	114	118	96	75	73	75	74	76	77	77	76	74	74	74	75	74	74				
CONDENSATE	73			160				160				165				150						
BOILER PRESSURE	10	18	23	23	22	21	23	21	20	22	24	19	21	23	20	21	20	21				
HEATING PRESSURE	0	1 1/2	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/4	1	2	2	2	2	2	2	2				
VACUUM GAUGE		10	10	12	11	11	9	10	10	11	10	9	9	10	9	8 1/2	10	10				
AVERAGE ROOM TEMP.	47.5	52.5	63.6	68.5	69.2	62.5	68.5	68.6	68.7	68.5	68.5	68.7	68.7	68.6	68.6	68.7	68.4	68.7	68.5	67.5	65.6	64.0
TEMP. DIFFERENCE	37.5	42.5	55.6	60.5	61.2	59.5	58.8	58.7	57.5	55.5	56.5	53.7	54.7	54.6	54.6	54.7	54.4	54.1	58.5	59.5	58.6	59.9

FIG. 9. TEMPERATURES TAKEN AT HALF-HOUR INTERVALS AT VARIOUS LOCATIONS IN THE SCHOOL.

The Temperature Difference: The curve in Fig. 10 was drawn to show the difference between the outside and inside temperature, and it represents the actual temperature range through which the heating plant was forced to heat the building.

Ventilation Tests: Air diffusion tests were made with finely divided strands of silk floss, arranged on a stand as shown in Fig. 11, which was placed in many positions and the movement of the strands noted. The results obtained were plotted as shown in Fig. 12. This sketch shows an air movement for each 5 ft. horizontal layer of air from ceiling to floor, as well as in three vertical sections through the room. This test was made while the pupils were pursuing their regular daily work.

The singular absence of lateral air currents within the breathing zone of the pupils will be noted. The air movement in this zone is uniformly down at the rate of about 2 ft. per minute.

The silk floss method was checked by turning steam into the room through the diffusers. The steam descended as a blanket across the entire area of the room. A "cascading" effect at the windows was quite noticeable; here the water vapor and air descended at possibly twice to three times the rate of the main blanket. A clear vision could be had entirely across the room until this blanket was 3 in. from the floor.

A second test of this kind was made in which the steam was allowed to flow through the duct until a layer was formed about 3 ft. in thickness; then the steam was turned off. In this case the steam blanket descended in a solid layer with air above and below it until it reached the floor. In this test lighted candles at each desk were substituted for the heat given off by the pupils

Temperature Canvass: A canvass was made of a typical room to determine the temperatures in the various parts of the room, such as at the diffuser, at the ceiling, in the heating zone, etc. These were made with five thermometers suspended on a cord from a stand. Temperatures were also taken near the windows. The temperatures are shown diagrammatically in Fig. 13. The thermostats in all rooms are set to maintain 60 deg. at the breathing zone. It will be noted that 95 per cent of the volume of this room are maintained at this temperature.

This fact is remarkable when compared with any of the systems previously mentioned in this paper. With the exception of the small zone surrounding the heating coils, there was but 2 deg. difference between the ceiling and the floor, and not 1 deg. difference in any part of the breathing zone. It will be noted that the temperature within 3 in. from the window pane, which was itself in a bay, was but 1 deg. cooler than the room. In fact, a person could sit on the window sill on this very brisk windy day and not experience the least discomfort.

No conclusion may be drawn at this time as to the economy effected by this system over the plenum system which it supplanted, but it may be stated that this system, with all its benefits over the preceding one, has not required any more fuel to operate. It will also be remembered that during the last heating season little or no choice has been possible as to the quality of the fuel obtained.

About its ventilating efficiency there can be no doubt. The air was seen to change in the room without draughts and without noticeable air currents. There could be no mingling of the exhalations of one child's body with that of another, neither would it be possible for the foul air being vented from the room to pass one or more children at their breathing line. The air passes straight downward with a velocity of about 2 ft. per minute, and when it is close to the

floor, creeps to the vent ducts and is exhausted. At the same time the air, which through contact with the window pane and exposed wall is cooled, passes out through those vent ducts nearest the outside wall, and is directly exhausted without mixing with the air in the occupied zone of the room. This prevents, very effectively, drafty floors.

The temperature canvass disclosed a feature which the author has never seen equaled in any other type of heating plant used for the heating and ventilating of a school house, namely the uniform temperature throughout the breathing zone and throughout the occupied portion of the zone which was noted in every room in the building heated by the Beery system. The humidity is maintained at 40 per cent relative. This, together with the other conditions maintained

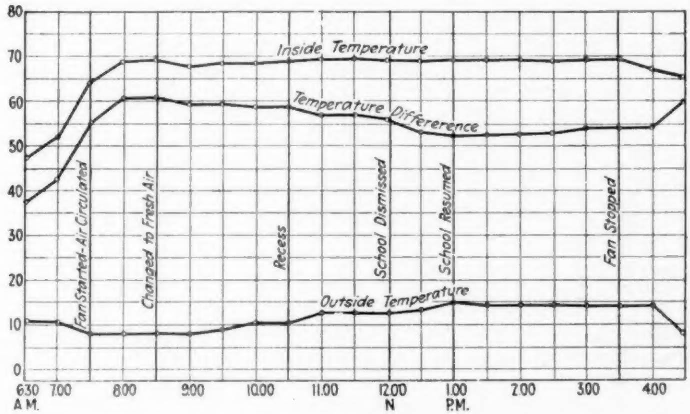


FIG. 10. TEMPERATURE CURVES FOR THE LINCOLN SCHOOL TEST, FEBRUARY 2, 1917.

by this system, makes a temperature of 67 to 68 deg. perfectly comfortable in the class rooms. Possibly the most striking illustration of the efficiency of the system is the general approval with which it was met by all the teachers who have worked in this school, and in other schools similarly equipped.

For the report of the foregoing tests and for the illustrations the author is indebted to Mr. G. H. Blanding, of the Johnson Service Company. The author was present only during part of the test and had no part in them. To Mr. Blanding and his assistants the credit is due for the methods followed and the results obtained.

In this test will be found some outstanding features and facts that should be of interest to the engineering profession. The entire theory and formula of the system of ventilation here referred to, are contradictory to generally accepted theory and require a differ-

ent line of reasoning and the laying aside of former ideas based on methods heretofore practiced.

This system operates on the displacement method, diffusing the air supply by producing downward pressure through the room ventilated; that is practically the entire volume of air for ventilation moves direct from the point of admission and diffusion until coming abruptly to the floor, where the pressure results in the air being discharged from a series of vents distributed around the room at the floor line. This eliminates lateral air movements and provides all individuals in the room with an air supply identically the same in temperature and volume, yet individual in operation and influence, so that it removes all sense of artificial heating conditions producing an atmosphere or ventilation condition which vitalizes.

Lateral air movements in the ventilated room (except in great volume and sufficient movement to emulate out-of-door diffusion) permit the various occupants of an inclosed space to inhale the undesirable physical compounds due to body ventilation and the exhalations of other people, with which the contents of the room become charged where the dilution principle is employed and static pressure relied upon to produce a given volume ratio of air discharge from the room, and the physical condition of the air in the room loses its efficiency to produce body ventilation in an energizing and invigorating manner.

There can be no doubt in the minds of reasonable people as to the veracity of the ventilating engineer in claiming that mechanical ventilating systems provide conditions which may be easily proven more conducive to the health of occupants than can be claimed for conditions where any scheme is employed that does not provide a positive manner for the conditioning, preparation and supply of air for ventilation.

There is also much justification in the defense of the physiologist who sets up the claim that he is not getting all he is paying for when after a careful and exacting process of purifying, warming and humidifying, the result of this effort and cost is lost in the room ventilated by the method used, which is too often the case, there being that absence of the vitalizing influence experienced out-of-doors and over which engineering arrangement and apparatus in the basement of the building have no control.

The foregoing remarks briefly represent the writer's conclusions and reply directly to the issue: open windows vs. mechanical ventilation. The mechanical engineer who designs and formulates plans for applying mechanical systems of ventilation to buildings has all the required equipment and rules by which to prove conclusively that enormous volumes of fresh air are being poured into buildings and that correct distribution to the various rooms according to their size is accurately accomplished, based upon the rule

of individual unit volume times number of people to occupy the building and upon which practically all legislative requirements are based.

He then proceeds to check the efficiency of the system in maintaining a desired temperature economically throughout the entire building and to further take measurements or calculations to determine how successfully the system is distributing the required volume to the different parts of the buildings requiring ventilation. If these tests determine that the system is delivering full measure in maintaining, tempering, conditioning and apportioning the correct air volumes, he too quickly concludes that the whole problem has been solved and the matter definitely settled. This attitude naturally results in aggravating the physiologist who does not interest himself in the mechanical problems, but senses the lack of entire efficiency when it comes to maintaining an energizing and stimulating ventila-

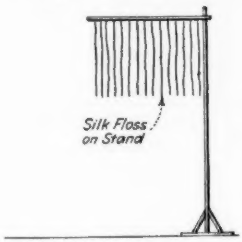


FIG. 11. APPARATUS FOR MAKING AIR DIFFUSION TESTS.

tion condition, even though the air may be scientifically measured, tempered and conditioned.

These criticisms are more frequent and justifiable in ventilated rooms where mental process and effort constitute the daily program. In industrial work where physical and manual effort is carried on, the individual maintains a certain degree of momentum entirely through the process of physical activity.

The first thing necessary to improvement in methods of ventilation should come from the ventilating engineers and should be in the form of a willingness to study and apply new theories and lay aside for the time old data and formulae. They should be ready to give an impartial try-out to any suggestions that are possessed of logic, whether they emanate from the physiologist, the engineer or the layman, and each individual should be willing to place his unbiased efforts at the disposal of public service and welfare. Through this policy only, will mechanical ventilation justify itself and come into its own, forever dispelling all controversy as to the merit of mechanical ventilation over any method which does not employ positive means of supply and control in its application to buildings.

The writer wishes to submit a health chart (see Fig. 14) based on five years' record of home visits by school nurses in the public schools of Rockford, Ill. The chart is arranged to show the monthly number of home visits per 100 pupils enrolled in the 18 schools, arranged in three groups according to the heating and ventilating conditions employed in the buildings. There are six schools in each group and they cover 18 of the 21 buildings in the city, a fact which in itself leaves practically no choice but to take the groupings as we find them. The first fact in general practice which must be taken into consideration is the one which determines where cases should be reported, that is, to the attendance department, or the department of school hygiene. It is always known with reasonable exactness when the child is absent, whether it be on account of some home

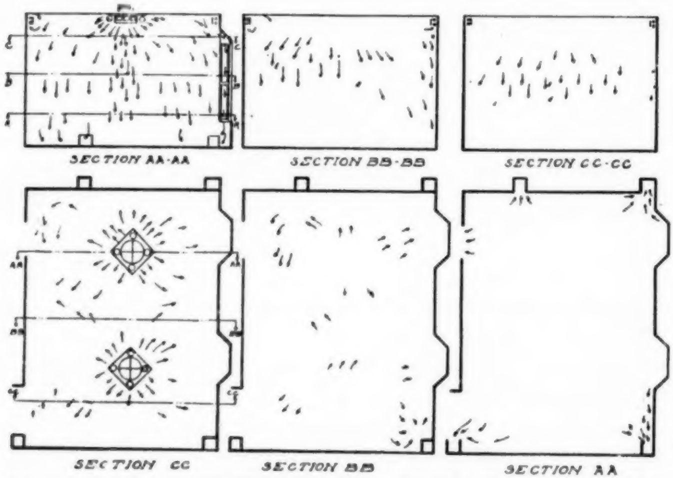


FIG. 12. DIAGRAM SHOWING RESULTS OF AIR DIFFUSION TESTS.

condition, indifference or reluctance on the part of the child or its parents, in which case the school authorities report such absence to the attendance department. Second, if there is no known circumstance unless it be a matter of health, the absence is reported to the department of school hygiene and the school nurse makes a home visit and records the case. The next possible chance or discrepancy occurs in the efficiency and diligence of the school authorities in reporting absence to either or both departments and in each group of schools will be found the minimum or maximum of efficiency in handling this part of school work. The third factor where discrepancy might occur is in the efficiency of operation of the heating or ventilating system in the various schools and the same rule applies that there are efficient operators in each group. It is the writer's belief based on years of familiarity with this school system, that in

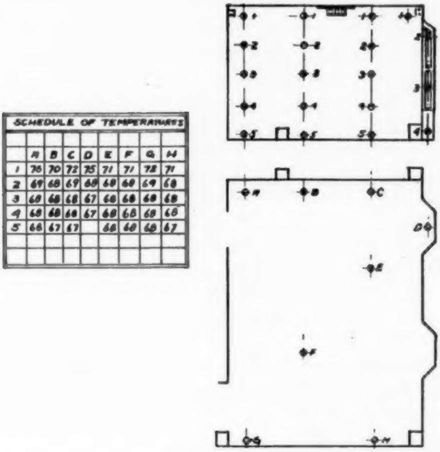


FIG. 13. TEMPERATURES IN A TYPICAL ROOM SHOWN DIAGRAMMATICALLY.

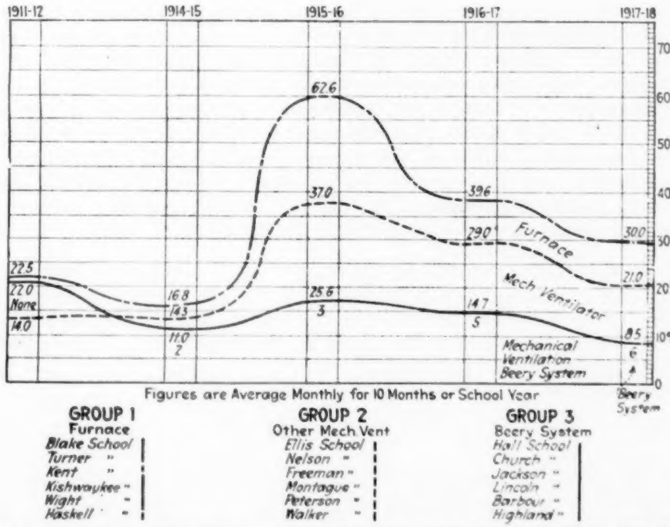


FIG. 14. CHART SHOWING MONTHLY HOME VISITS BY SCHOOL NURSES PER 100 PUPILS ENROLLED IN EACH GROUP OF SIX SCHOOLS, ROCKFORD, ILL.

the matter of reporting absences, the group No. 2 schools will suffer the greatest discrepancies, that in the matter of operation the group No. 3 schools have the widest discrepancy in efficient operation of system. The latter is because one modern large school building of group No. 3 has had five different operators during the two years of its existence; that another has had four changes in three years due largely to unsatisfactory remuneration of employees. The school year 1915-16, is abnormal due to a scarlet fever and measles epidemic, causing an unusually large number of home visits in all buildings.

By reference to the chart, the reader will observe that through the school years of 1911-12, the conditions in the third group of schools were the same as found in groups 1 and 2; also that the Beery system does not enter the chart until the school year 1914-15, during which year two of the group 3 schools had this system. During the next year one more had been added and at the beginning of the years 1916-17, two more Beery systems had been installed and at the beginning of 1917-18, the sixth school had been equipped.

The chart further shows the relative health condition as between groups 1 and 2. In group 1, four of the buildings had gravity furnace heat and ventilation and relied upon open windows for such fresh air as the occupants were able to receive. Two of the group 1 buildings had the fan furnace system with automatic control on dampers supplying heated and tempered air. In the group 2 buildings, four have the straight fan-blast heat and ventilation, with direct radiation in corridors and entrance ways, and automatic regulation controlling dampers on warm and tempered air chambers. All of these buildings in groups 1 and 2 are of brick with wood floors, framing and stairways and are in good repair generally. Two of the group 2 buildings are of fireproof construction, one having straight fan blast, the same as above described buildings. The second had in addition to this, cast-iron radiation in all rooms, with modulated hand control.

The third group as before stated, had in 1911-12, two buildings equipped with indirect fan heating and ventilation plenum system; three had gravity furnace heating equipment, and one being a new fireproof building, enters the chart at the beginning of the school year 1916-17.

No. 556

ATMOSPHERIC HEATING SYSTEM FOR RAILROAD CARS

By Thos. H. Ireland[1], St. Paul, Minn.

Non-Member

AMONG the recent contributions of the science of heating to the comfort of the human being, there have been few more radical in their reversal of old established custom than the method adopted by one of the large lumber companies for the welfare of its men. The conditions in the average lumber camp are well known. There are usually several buildings, dignified by the names of office buildings, bunk houses and mess halls, built of logs and heated with wood stoves, so arranged that one is alternately roasted and frozen.

The management of this company, the Park Falls Lumber Co., Park Falls, Wis., recognizes the fact that improved living conditions mean contented labor and that contented labor means a better product and a better profit. To secure these conditions they conceived and put into operation an improved lumber camp affording all the comfort of a permanent structure and yet portable so that it could be moved to any part of the vast forests in which timber was being cut.

This model lumber camp consists of twelve railroad cars, specially designed and built by the Company's mechanical department, which is equipped with the most complete and modern machinery for building cars, locomotives and other appliances used in the lumbering industry. The twelve cars are arranged as shown in Fig. 1 and are used for the following purposes:

Power Car—Contains the boiler, engine, electric lighting system, hot and cold-water systems and the atmospheric heating system.

Kitchen Car—Contains the supply room, cook's bed room and kitchen.

Office Car—Contains the wash room, fitted with modern plumbing fixtures, office, two sleeping rooms and sitting room comfortably furnished.

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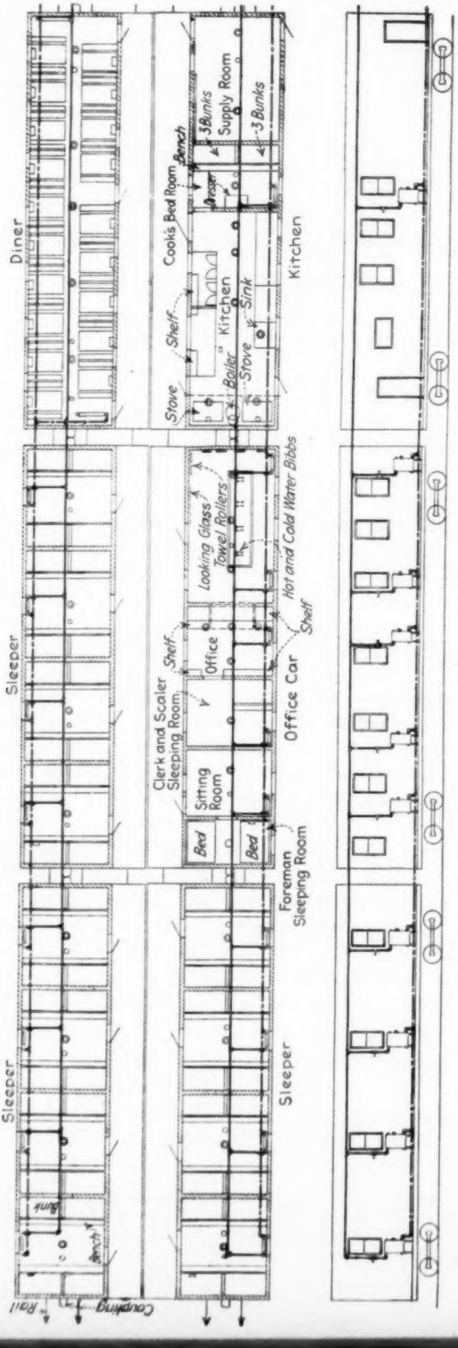
[1]Crane and Ordway Co., Fifth and Rosabel Sts., St. Paul, Minn.

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, January, 1920.


Diner
Cook's Bed Room
Bench
3 Bunks
Supply Room
3 Bunks
Dresser
Shelf
Kitchen
Sink
Kitchen
Stove
Boiler
Stove
Looking Glass
Towel Rollers
Hot and Cold Water Bibbs
Shelf
Shelf
Office
Clerk and Scaler Sleeping Room
Office Car
Sitting Room
Bed
Bed
Foreman Sleeping Room
Sleeper
Sleeper
Sleeper
Bunk
Bench
Rail
Coupling

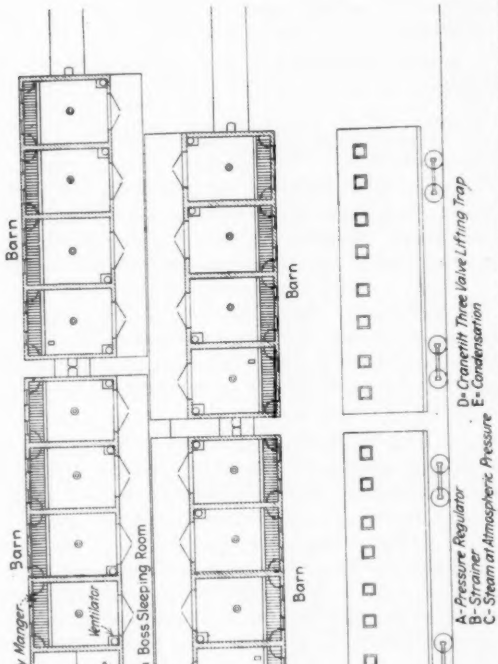


FIG. 1. DIAGRAM OR 12-CAR TRAIN FORMING PORTABLE LUMBER CAMP OF PARK FALLS LUMBER CO., SHOWING APPLICATION OF CENTRALLY OPERATED STEAM HEATING SYSTEM.

SLEEPING CARS—Three sleeping cars, each having four compartments fitted with sanitary bunks and each compartment accommodating 8 men.

DINING CAR—Fitted with 19 tables and rigid seats and comfortably accommodating 114 men.

SHOP CAR—Contains three compartments used for saw filing, general repairs and blacksmith shop.

HORSE CARS—Four cars arranged to accommodate 32 horses.

The management decided to equip the cars with many of the modern improvements, including an electric lighting system, hot and cold water service and a steam heating system that would suitably heat the cars both in mild and severe winter weather. (Severe weather in the vicinity of Park Falls means 40 deg. fahr. below zero.) There were certain restrictions imposed for the proposed heating system, the principal one being that all steam and condensation piping must be inside of the cars, except where connections were made between the cars.

As water had to be hauled several miles in a tank car from the water supply to the camp cars it was necessary that all condensate be returned to the boiler, and it was also desired to return the condensate to the boiler, which is fired by wood, at the least cost in fuel and water. This rather novel problem was solved by recommending an atmospheric heating system, with steam trap for return of condensation, similar in arrangement to a central station heating system which was installed for this company and has been in operation since October, 1913, heating more than twelve buildings.

The following arrangement was decided upon and put in operation November, 1914.

The power car contains a locomotive-type firebox boiler, maintaining an average steam pressure of 125 lb. gage. Steam flows through a Crane pressure regulator into a 2 in. pipe, having its pressure reduced from 125 lb. to 1 lb. gage at the regulator.

There are seven cars heated with steam. Each car is fitted with American Radiator Co. water-pattern two-column 38 in. radiators, having ½ in. tapping at top end for steam supply and ½ in. eccentric tapping opposite bottom end for condensation outlet. Each radiator is set on extension legs having the condensation outlet 16 in. above the car floor.

The cars heated with the Cranetilt trap atmospheric heating system are the kitchen, office, three sleepers, dining and shop cars. There is a 2 in. pipe having 2x2x½ in. cast-iron tees, suspended from the ceiling of each car, which is used to supply the steam to the radiators. The 2 in, pipe is connected from one car to another with a section of steam hose and two Crane railroad unions, making a better connection for the service than the regular train line hose coupling, because when the connections are made they

remain tight and eliminate the use of a gasket packing. The steam main is connected to the top end of each radiator with ½ in. pipe, having a brass seat and disc globe valve and Crane No. 592 railroad union elbow. There is a 1¼ in. pipe having 1¼x1¼x½ in. cast-iron tees suspended from the radiator extension legs and the wall in each car, which receives the condensation from the radiators.

The condensation pipe is several inches above the floor of the train for the purpose of cleanliness. The condensation pipe is connected between each car with the same arrangement of steam hose and railroad unions as described for the steam supply pipe connections. The condensation main is connected to the condensation outlet of each radiator with ½ in. pipe, having an automatic condensation valve.

Each radiator is fitted with a valve which permits the occupant of any compartment to graduate the quantity of steam admitted to the radiator in order to have the compartment comfortable. This has been found to be a very convenient and economical arrangement, especially in mild winter weather when it is too cold to be entirely without heat and too warm with 100 per cent of the heating surface exposed to the action of the steam. Each radiator is also fitted with a Hoffman air valve so fastened so that it cannot be turned unless extraordinary force is applied.

The lumber jack gets very wet out in the woods at times and the moisture from both perspiration and the weather contribute to odors that make ventilation imperative. The management put forth every effort to make the cars healthful and has provided suitable ventilating devices, so that, when it is raining or snowing, it is not necessary to open the doors and windows to admit fresh air.

When the steam is condensed and at atmospheric pressure, the condensation is reclaimed and discharged into the boiler having a steam pressure of 125 lb. gage, as follows:

The main condensation pipe from the cars is connected to the condensation inlet of a three-valve lifting trap suspended below the deck of the power car. All condensation from the heating system, also from the coil in the hot-water storage tank, flows into this trap, until it has reached its capacity. As the trap is accumulating the condensation, its tank gradually tilts, but the valves do not move until the trap overbalances and then with a quick movement it operates the valves simultaneously, by closing the vent and inlet valves and opening the steam and discharge valves, discharging its contents to a receiving tank above the boiler. After it has discharged, it will again quickly operate the valves, closing the steam and discharge valves and opening the vent valve, thus releasing the live steam from the tank of the trap into the low pressure steam main, and permitting the condensation to again flow through the inlet valve. The operation is made in 12 seconds.

Provision is made so that the low pressure steam does not enter the trap through its vent valve when opened while the trap is in a

filling position. The receiving tank receiving the condensation from the trap also receives the fresh make-up water necessary to maintain a normal water line in the boiler.

The outlet of the receiving tank is connected to the inlet of a direct-return trap. The discharge outlet of this trap is connected to the blow-off connection of the boiler. There is a direct live steam connection between the boiler and the steam inlet of the direct-return trap. The vent outlet is connected to the low pressure heating main. The direct-return trap receives its capacity from the receiver and discharges the water directly into the boiler; it is entirely automatic and handles the water at any temperature and eliminates any use of oil in the steam and discharges no steam into the atmosphere as is frequently done with a steam pump.

This atmospheric heating system is flexible in operation as it can be operated with steam in the radiators at a pressure below or above atmosphere. The advisable maximum pressure with cast-iron radiators, is 25 lb. gage.

The lumber company has been operating the above camp cars ever since November, 1914, and expresses itself as being satisfied with the excellent results it has obtained with the atmospheric heating system and with the low maintenance cost.

No. 557

PULVERIZED FUEL

By E. R. Knowles[1], New York, N. Y.

Non-Member

THE maximum productiveness of anything is attained when every iota of value therein is made to perform to the utmost its allotted part in the total scheme of utilization, and the more nearly this is attained the more nearly perfect is the result.

This statement holds good in all directions and is particularly applicable to the topic under discussion—pulverized fuel—showing, as it does, the results which have been attained by the continued improvement of the physical condition of the fuel and the methods of its combustion.

In the early days, when the use of coal for heat was first discovered, it made very little difference what kind, or how crude in form the fuel was, or how inefficient was its method of utilization, so long as the fuel fulfilled its purpose and gave the desired heat. But as its use became more general, and greater demands were made, it was very quickly perceived that some fuels gave better results than others and a selective action took place, the poorer fuels being discarded for the better. With the increasing demand came a corresponding scarcity of supply, causing greater care in the use, and greater efforts toward conservation in the methods of application; these processes of natural selection and the survival of the fittest are still in full operation.

The results of these processes, at the present time, are to be seen in the limited number of fuels in commercial use; in the careful selection as to quality and grading to meet varied commercial requirements and in the very many and various methods of their utilization in vogue; all tending more or less to complete and perfect utilization.

Broadly speaking, fuel is any material which can be made to combine with other material in such a way as to liberate heat. Commercially, fuel is any material the greater part of which can be made to combine with oxygen (of the air) and so liberate heat.

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Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, January, 1920.

A perfect fuel is one which is composed entirely of substances which will completely unite with oxygen and in so doing liberate a maximum of heat. Pure carbon may be cited as a perfect fuel in that it will completely unite with oxygen, forming carbon dioxide, but fuel in this form is not available for commercial use The nearest approximations to a perfect fuel are found in natural gas and fuel oil.

Fuel in some form is one of the most important items in the cost of industrial production, and on its low cost and efficient utilization the values of all manufactured products largely depend.

Fuel may be divided into two classes, natural and artificial. Natural fuels comprise: coal, crude oil or petroleum, natural gas, wood, lignite and peat. Artificial fuels comprise: coke, charcoal,

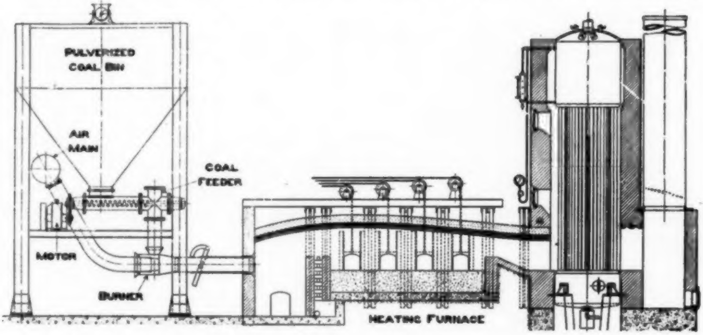

FIG. 1. BILLET HEATING FURNACE USING PULVERIZED FUEL.

distillation products of petroleum, artificial gas, briquettes of coal, hydrogen gas, acetylene gas and alcohol.

The discovery of coal and its value as a fuel marked the beginning of the wonderful industrial era in which we now exist, and from the time of its first use until the present time, constant improvements have been made in the methods of its application and efficiency of utilization.

In addition to coal, two other forms of fuel, crude oil or petroleum and natural gas, both of more recent discovery, have become most important sources of fuel supply, and the methods of application and efficiency of utilization have also been constantly improved.

Coal, the first and most universally used and most dependable fuel, was known to man 200 years B. C., although its latent powers were not recognized for nearly 2,000 years before the beginning of the present industrial era.

Coal received its first great industrial impulse with the invention of the steam engine in 1784, and its use from that time to the present, not alone for the generation of power but also for domestic use and many and various other purposes, has increased enormously.

In 1910 the United States alone produced about 502,000,000 tons of coal, and in 1915 about 532,000,000 tons; during the years 1916 and 1917 the great increase in industrial development increased this annual rate to 590,000,000 and 655,000,000 respectively, and similar conditions may be said to have obtained in a measure in other parts of the world.

The demand is ever increasing, but the supply of coal is apparently inexhaustible; it is the one dependable fuel for hundreds of years to come.

Great improvements have been made in the methods of utilizing coal as a fuel, from the first crude use in varying-size lumps, hand fired in crude and inefficient forms of boilers, to the present day practice of using finely-graded coal, mechanically fired in the most efficient types of boilers.

Notwithstanding all this advancement and improvement, present boiler practice with the best equipment wastes from 25 to 35 per cent of the heat value of the fuel consumed, and this of a grade of which the cost is high and constantly increasing.

Mineral oil or petroleum, the second and next in order of importance, has been known in various forms and under various titles, the world over from the earliest times, but was little understood or used.

After its discovery in quantity in Pennsylvania in 1859 the oil era began, and in 1861, its production was a recognized industry. Since that time its uses for industrial, domestic and many other purposes have increased with marvelous rapidity and it is now used successfully as a fuel for open hearth furnaces; copper, lead, tin, zinc, nickel, silver, iron and other metal melting furnaces; steam boilers; drying ovens; ore roasting; calciners; hot air furnaces; sand drying, etc.

Its great value as a fuel is due to the fact that the heat is at all times under perfect control, so that a constant temperature may be attained and maintained at the will of the operator.

In 1894 over 50,000,000 barrels (42 gal. per barrel) were produced in the United States alone; in 1906 the production was 126,500,000 barrels; in 1917 about 335,000,000 barrels, and at the present time the demand is increasingly greater than the production, notwithstanding the opening up of new sources of supply. The cost is also correspondingly increasing so that, notwithstanding its great advantages and all the improvements in its economical use as a fuel, it is a serious problem how far the use of mineral oil can be continued before the supply begins to fall off and its cost becomes prohibitive.

Natural gas, the third of the principal fuels, is limited in scope, coming out of the ground as does mineral oil, but unlike mineral oil as respects transportation, it can only be distributed in pipes for limited distances.

At first it was considered as a by-product of the petroleum districts, and was used in a limited way for heating and illumination. It was first used in Fredonia, N. Y., in 1826, and was distributed in pipes in Titusville, Pa., in 1872. In 1883 its first great use began, since which time there has been an extraordinarily rapid development in its application to industrial light, heat and power purposes, in the territories where it is obtainable.

In 1907 the total annual consumption in the United States was about 400,000,000,000 cu. ft., and in 1914 was about 592,000,000,-

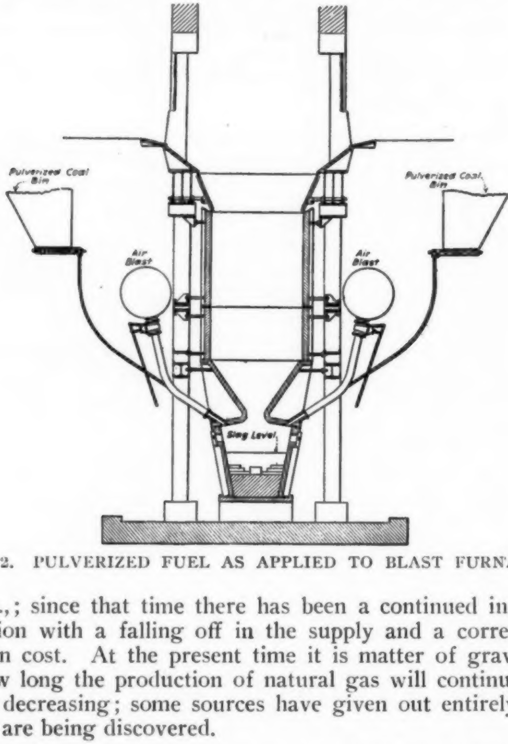

FIG. 2. PULVERIZED FUEL AS APPLIED TO BLAST FURNACE.

000 cu ft.,; since that time there has been a continued increase in consumption with a falling off in the supply and a corresponding increase in cost. At the present time it is matter of grave uncertainty how long the production of natural gas will continue, as the supply is decreasing; some sources have given out entirely and no new ones are being discovered.

The great value of natural gas as a fuel and an illuminant was early recognized, but its limitation to the territory where it was obtainable prevented the extended use as in the case of coal or mineral oil. Efforts to overcome this difficulty ultimately resulted in the introduction of artificial gas, which at the present time has an almost universal application.

At first the artificial product was known as illuminating gas, a result of the destructive distillation of coal. It was discovered by

William Murdock in 1792 and was used to illuminate London, England, in 1812. Since that time, the methods of production have been greatly improved and the cost reduced; at the present time, in the form of water gas its use has become almost universal for heat, power and lighting purposes. In 1914 the production in the United States was about 592,000,000,000 cu. ft., which figure is greatly exceeded at the present time.

In order to overcome the necessity of distributing artificial gas through a more or less elaborate piping system which militated against its general use in many cases, an improved method of manufacture known as the producer gas system, has of late years been introduced, by means of which artificial gas can be manufactured in small units and locally used, thus providing means for its general utilization for all possible purposes. Producer gas was first devised by Siemens in 1864, improved by Moller in 1878 and Krupp in 1881. The first successful type of suction gas producer was devised by Crossley in 1901 since which time many improvements have been made and many forms of gas producers have been introduced, until at present, producer gas is one of the most, if not the most flexible, economical and widely used form of fuel.

From these general statements it will be seen that the uses of these three principal fuels, coal, oil and gas, have been and are constantly increasing in variety and volume, and at the present time, due to the enormous demands, and the widespread and lavish use on account of the war and other reasons, production can hardly keep pace with the demand. As a consequence costs have greatly increased, and are rapidly reaching a point where serious consideration must be given, not alone to the conservation of present forms of fuel, but also to the utilization of unused and cheaper forms of these and other fuels, and to the development of the ultimate values thereof.

Of these fuels, mineral oil and artificial gas have been so improved in the processes of manufacture and the great variety of methods of application, that all are extremely flexible and economical in practice; but the supply of mineral oil is not equal to the demand and its cost is rising to a prohibitive point; likewise distributed artificial gas is largely dependent on mineral oil as respects cost of production. On the other hand coal, the most widely spread and dependable fuel, the applications of which have been greatly improved and economized, has not yet reached the maximum utilization.

The application of the gas producer has made a great step in advance in this direction, but there still remains a large percentage of fuel value in coal which must be recovered, in order to reach the maximum utilization; means must be devised whereby the cheap, low grade and waste coals may be successfully utilized as well, as a substitute for the graded high cost coals now in general use.

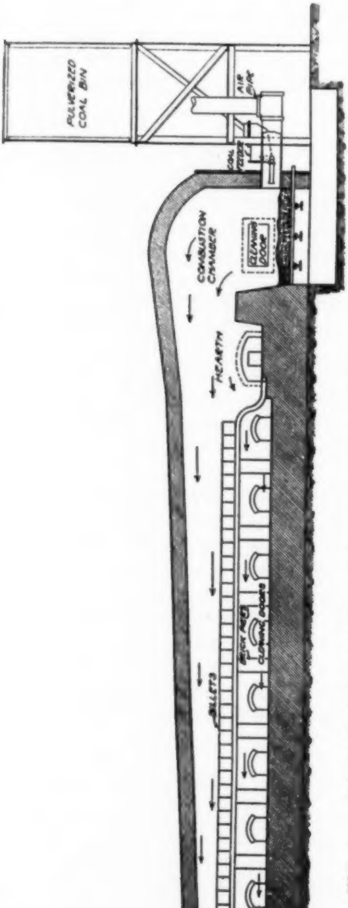

FIG. 2-a. CONTINUOUS HEATING FURNACE USING PULVERIZED FUEL.

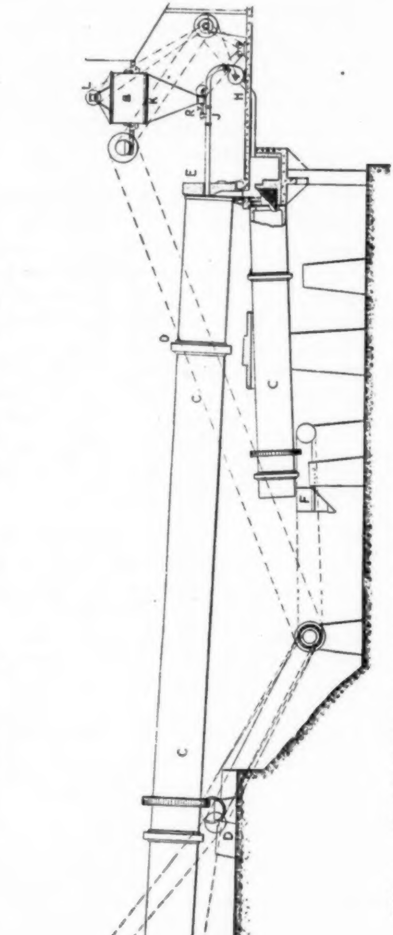

FIG. 3. APPLICATION OF PULVERIZED FUEL TO CEMENT KILN.

In various papers on Fuels[1], Dust[2], Smoke[3], Pulverized Coal[4], Saving of Coal in Boiler Plants[5], Coal Conservation[6] and Stokers vs. Pulverized Coal[7], I have endeavored to give the history, character and applications of the various fuels in commercial use; their relative values and efficiencies; their wastes and the various ways in which these wastes can be eliminated and prevented; the ultimate forms of commercial fuel which will give a maximum—100 per cent—combustion and means by which these results can be efficiently and economically attained.

That present methods of fuel combustion are, in the great majority of cases, wasteful in the extreme; that the present cost of fuels most largely in use is abnormally high; that careful conservation of fuels is most important and that any method by means of which these conditions can be overcome and a maximum of efficiency attained at a minimum of cost is most desirable and imperatively necessary, admits of no argument.

Such conditions actually exist at the present time, and the solution of these problems is one which is engaging the close attention and investigation of many engineering experts, all working toward the same end, how best to attain a maximum output from a minimum amount of fuel at a minimum of cost.

The author is of the opinion that the ultimate future fuel for domestic and commercial purposes will be a gas or near gas; natural or artificial gas or oil and its products for domestic purposes, and pulverized fuels such as coal in its various forms, bituminous, anthracite, and lignite with their intermediaries, which when properly mixed with the requisite amount of air, become a coarse or near gas, for commercial purposes.

Mr. W. O. Ranken, engineer of the Quigley Furnace Specialties Company, has made a careful estimate of the comparative operating costs of fuels figured on a B. t. u. basis, assuming that there are 19,000 B. t. u. in a pound of oil and an average of 13,500 B. t. u. in a pound of bituminous coal, and that gas producers will give 85 per cent efficiency; he finds that fuel oil at 4¾ cts. per gal. will give 28,600 B. t. u. for one (1) ct.; producer gas from run of mine coal at $3.10 per ton, will give 69,673 B. t. u. for one (1) ct.: pulverized coal, slack, at $2.75 per ton wlll give 98,181 B. t. u. for one (1) ct., or a ratio of values of oil: gas: pulverized coal:: 1 :2.45 :3.43.

When we consider the nature of combustion (the chemical union with each particle of combustible of the requisite amount of oxygen), it is apparent that the finer the particles of the combustible are, the more nearly can such a condition of complete combustion be attained.

[1] Fuels, published in *Steam*, August, 1918.
[2] Dust, published in *Steam*, August, 1917.
[3] Smoke, published in *Steam*, January, 1919.
[4] Pulverized Coal, published in *Steam*, October and November, 1918.
[5] Saving of Coal in Boiler Plants, published in *Steam*, April, 1919.
[6] Coal Conservation, published in *Steam*, March, 1919.
[7] Stokers vs. Pulverized Coal, published in *Steam*, July, 1919.

Gas and oil have all of their combustible content in an extremely finely divided state and when mixed with the requisite amount of air, are almost instantaneously and completely oxidized and consumed, liberating the maximum amount of heat units attainable from them.

A fuel, such as coal, in lump form, cannot function in such a manner. A lump of coal, say a cube of 1 in. linear dimensions, exposes 6 sq. in. of surface for oxidization which takes place at first only on the surface and then gradually creeps into the interior of the lump, which in time is more or less consumed.

If, however, this 1 in. cube is so finely pulverized that 85 to 95 per cent of it will pass through a 200 mesh sieve, it will expose something like 30 sq. ft. of surface to almost instantaneous and complete oxidation. In this finely pulverized state, the nature of

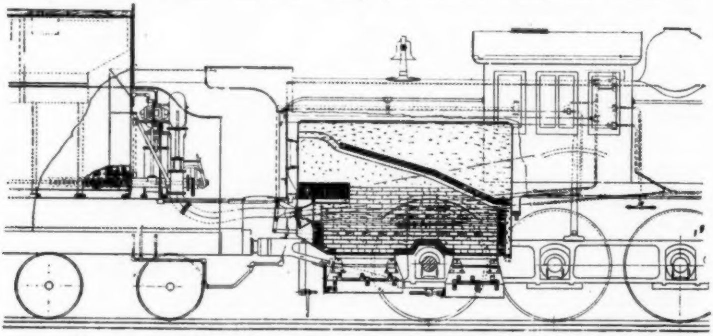

FIG. 4. APPLICATION OF PULVERIZED COAL TO LOCOMOTIVE.

the coal is not altered, but its form is changed from a solid to one having liquid properties. When mixed with air it becomes the equivalent of a coarse gas and burns as such with complete—100 per cent—combustion and liberates the maximum amount of heat units obtainable therefrom.

In other words, the more finely the fuel is subdivided, the more nearly it approximates a true gas and the more nearly it functions as such. From this it would appear that pulverized fuel, when properly made and applied, will give the highest efficiency of combustion attainable from a solid fuel.

That fuels in a finely divided state will combust in the most complete, efficient and economical manner, has become so definite and is so well known that it is hardly necessary to reiterate this statement. Numerous writers on this subject have so stated and many successfully operating combustion plants using finely divided fuels bear witness to it, but the means by which this fine division can be attained and this most complete combustion accomplished in the most efficient and economical manner, is not as yet so definitely and successfully worked out.

The earliest recorded effort to burn coal in powdered form was that of Niepce in 1818. Henchel did work along this line in 1831.

In 1861 John Bourne, in his Treatise on the Steam Engine, says: "It appears to us that the fuel and the air must be fed in simultaneously, and the most feasible way seems to be in reducing the coal to dust, and blowing it into a chamber lined with fire brick, so that the coal dust may be ignited by coming in contact with the red hot surfaces."

Crompton made the next attempt in 1868. In 1873 powdered coal was used in a rotary puddling furnace at the Woolwich Arsenal, England.

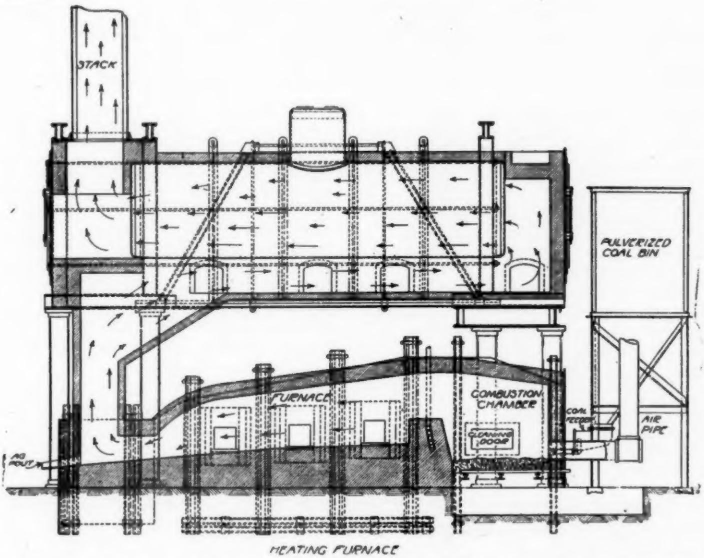

FIG. 5. TYPICAL APPLICATION OF PULVERIZED FUEL TO HEATING FURNACE WITH WASTE-HEAT BOILER.

In 1876, Wepley and Storer were interested in the work, then Unger, Friedeberg, DeCamp, Ruhl, R. Swartzkopff and McCantry about 1881, Wegner in 1891, Hurry and Seaman in 1894.

In 1895 the Atlas Portland Cement Company successfully burned powdered coal in their cement kilns and it has been in continuous use by the cement industry since that time.

In 1896 the Manhattan Elevated R. R. Co., New York, experimented with its use in some of its locomotives. In 1904 experimental work was tried on steam boiler furnaces and the Bettington boiler, a special form designed for the purpose, was the outcome of such experiments.

In 1905, J. R. Culliney, supt. of the American Steel & Iron Mfg. Co., made the first application of pulverized coal to its metallurgical furnaces; its final and satisfactory use in these furnaces was established in 1911, through the work of Sorensen, Shelby, Brown and Warford.

In 1912 an installation was made on stationary boilers at the M. K. & T. Ry. shops at Parsons, Kansas, and is now operating with marked success; in 1915 a steam boiler at the American Locomotive Company works, Schenectady, N. Y., was equipped to use pulverized coal as a fuel and has been in successful operation ever since.

In the United States there have been used to date over 50,000,000 tons of coal in powdered form; there are about 6,000,000 tons of powdered coal now used annually in cement making; about 2,000,000 tons in copper roasting and smelting; about 2,000,000 tons in steel manufacture and about 200,000 tons for general power. Powdered coal is now successfully used in heating furnaces of the following types:

Annealing ovens
Bar heating furnaces (see Fig. 1)
Blast furnaces (see Fig. 2)
Busheling and puddling furnaces
Calcining furnaces
Continuous heating furnaces (see Fig. 2a)
Core and mold drying ovens
Case hardening furnaces
Distillation furnaces
Drying furnaces
Forges, smithing, etc.
Galvanizing pots
Heating, reheating and forging furnaces (see Fig. 5)
Melting furnaces (see Fig. 6)
Nodulizing furnaces
Open hearth furnaces (see Fig. 7)
Oil stills
Ore roasting and smelting furnaces
Puddling furnaces (see Fig 8)
Pipe welding furnaces
Reverberatory furnaces
Rotary cement kilns (see Fig. 3)
Rotary lime kilns
Soaking pits (see Fig. 9)
Sheet and pair furnaces
Sintering furnaces
Steam boilers
Steam locomotives (see Fig. 4)

Its use in steam boilers, locomotives, etc., is steadily increasing; new applications are constantly and successfully being made, and it would appear that this method of fuel combustion is now so perfected that it is far in advance in the solution of the problem of determining the most economical and efficient method of fuel utilization. It is the most efficient fuel for general use.

The development and perfecting of means and processes of preparing and burning powdered coal have been along lines naturally to be expected. Early experiments were crude and failed largely from lack of knowledge of the necessary conditions for its satisfactory use, and lack of the proper machinery for reducing the coal to a proper degree of fineness.

The first effort was made to burn fine slack by blowing it over, or upon, the surface of a burning fuel bed, by use of a steam jet; later by crushing and grinding the coal to what at that time was considered a fine size, and blowing it into the furnace with what was deemed the requisite amount of air necessary for combustion.

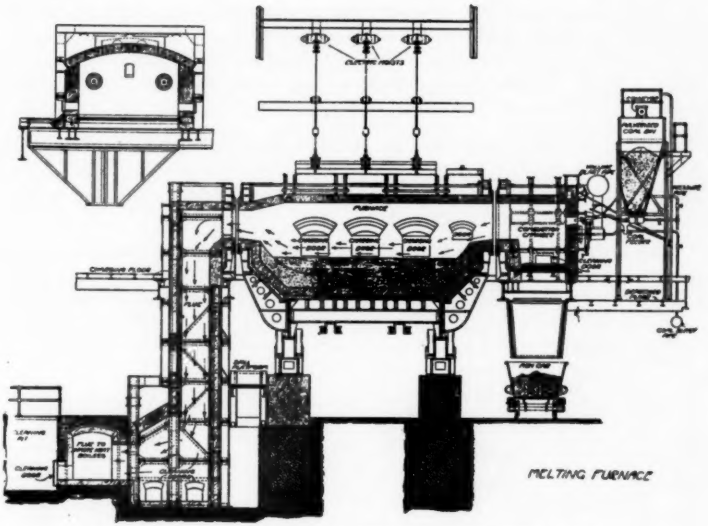

FIG. 6. MELTING FURNACE USING PULVERIZED FUEL.

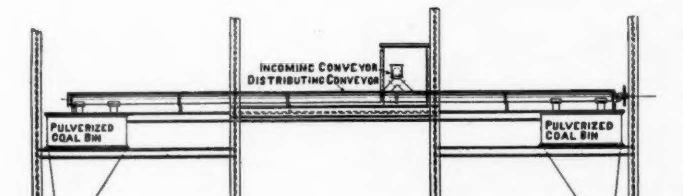

FIG. 7. APPLICATION OF PULVERIZED FUEL TO OPEN HEARTH FURNACES.

It was not fully appreciated for some time that the coal must be so finely pulverized that it would burn while floating in the air in the form of a dust cloud; but it was finally proved that powdered coal would burn under these general conditions and develop a very intense heat. After this its development and application made rapid progress.

Practically any coal can be burned in pulverized form with a properly constructed furnace and burning equipment, but each application must be governed by the quality of the fuel available in the district in which it is employed.

This method of burning coal has brought into consideration, and within reach of a great many consumers, coal such as lignite, mineral coals, cokebraize, anthracite and bituminous, screenings, washery-waste, culm and slack, from which hitherto very inefficient results were obtained.

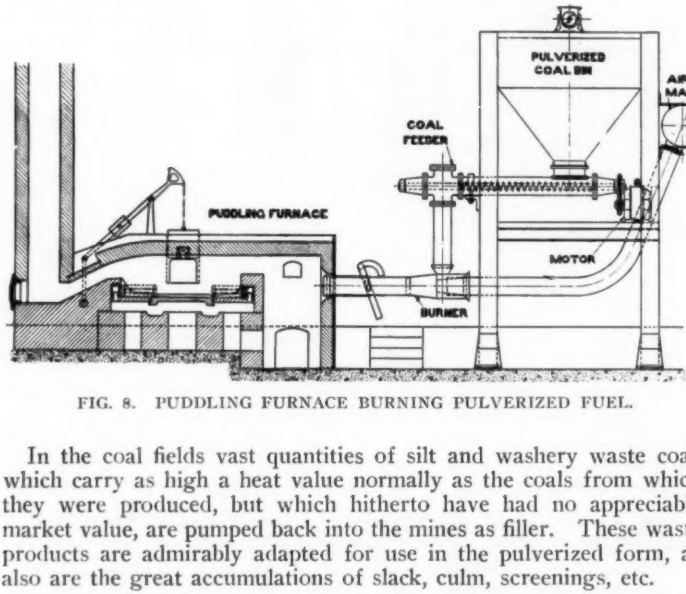

FIG. 8. PUDDLING FURNACE BURNING PULVERIZED FUEL.

In the coal fields vast quantities of silt and washery waste coal, which carry as high a heat value normally as the coals from which they were produced, but which hitherto have had no appreciable market value, are pumped back into the mines as filler. These waste products are admirably adapted for use in the pulverized form, as also are the great accumulations of slack, culm, screenings, etc.

Coals low in volatile matter and high in fixed carbon content, such as anthracite and semi-anthracite, coke and charcoal, are exceedingly hard to ignite in the pulverized form, and cannot be burned satisfactorily unless the furnace into which they are injected is of special construction and in an incandescent state. There is too much tendency toward a "puffy," irregular condition of flame and to undesirable extinction.

Clean coal is essential to economical and efficient operation. Coal is too expensive for the consumer to pay for slate, dirt, tramp metal,

excess moisture, and other extraneous matter, as has been the prevailing custom to a greater or less degree.

The preparation of the coal should begin at the mine where it should be properly cleaned and the clean coal ruling instigated during the war by the Fuel Administration should be continued and rigidly enforced, and no consumer should be compelled to purchase or use a coal which is not clean and entirely combustible except the percentage of ash which is an inherent part of it.

Due to the high temperature of combustion and the complete combustion of all of the fuel, powdered coal makes a smokeless fire at

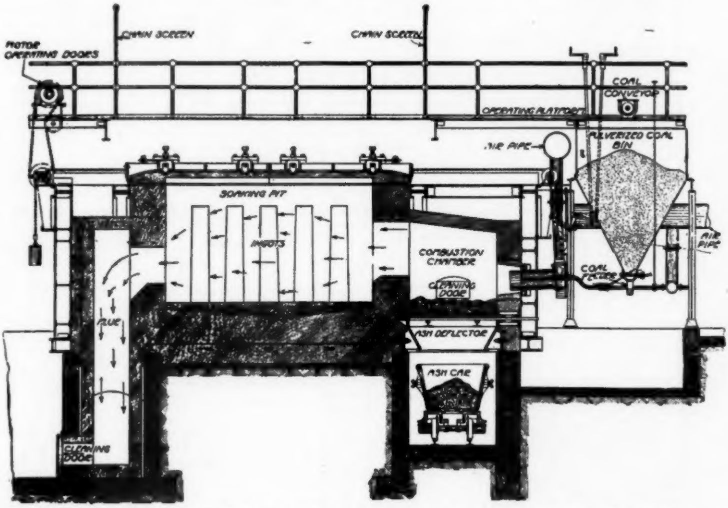

FIG. 9. SOAKING FURNACE IN WHICH PULVERIZED FUEL IS USED.

all rates of burning, and, as the ash is very fine, a large percentage of it passes into the flues and up the chimney, greatly reducing the amount of clinkering and slagging. Again, the presence of sulphur while it has no ill effects in small quantities in heating and annealing furnaces, must be given careful attention when occurring in connection with the reduction and refining of metals and ores.

The presence of a high percentage of moisture in the coal renders it difficult to pulverize, and while pulverized coal containing a high per cent of moisture has been successfully burned, there is a decided tendency to clog and pack in the distributing systems of piping in use in the present forms of pulverized coal apparatus. Excessive moisture causes irregular combustion and may even extinguish it altogether. Dry coal is required to obtain continuously successful results.

Generally speaking, therefore, fuel used in the powdered form has a restricted range both as to species and quality. It has been

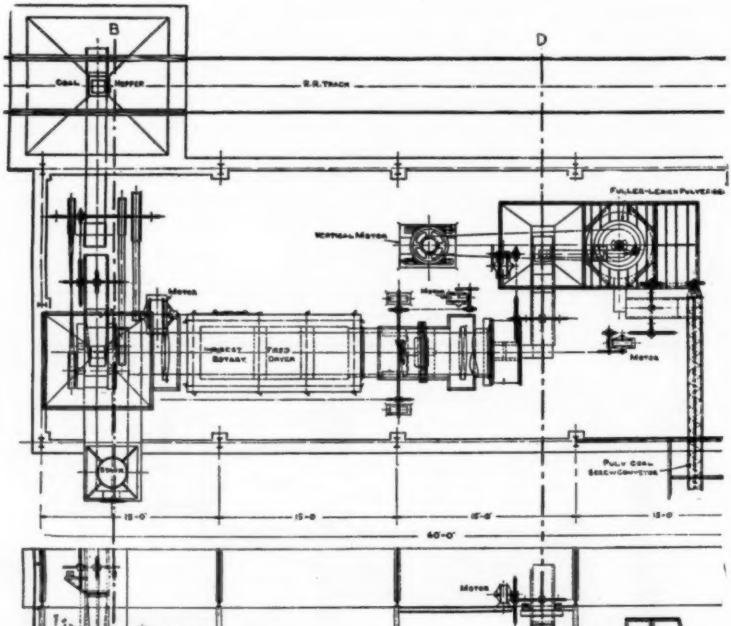

FIG. 10. PLAN AND ELEVATION OF PLANT FOR PULVERIZING COAL.

found that bituminous coal, due to its high volatile content, is the most desirable for burning in the pulverized form, and that the very best results are obtained by the use of the best grades of bituminous coals, high in volatiles and low in ash and sulphur. The higher the volatiles, the more readily and continuously will the coal burn in the furnace, and the more easily will it ignite.

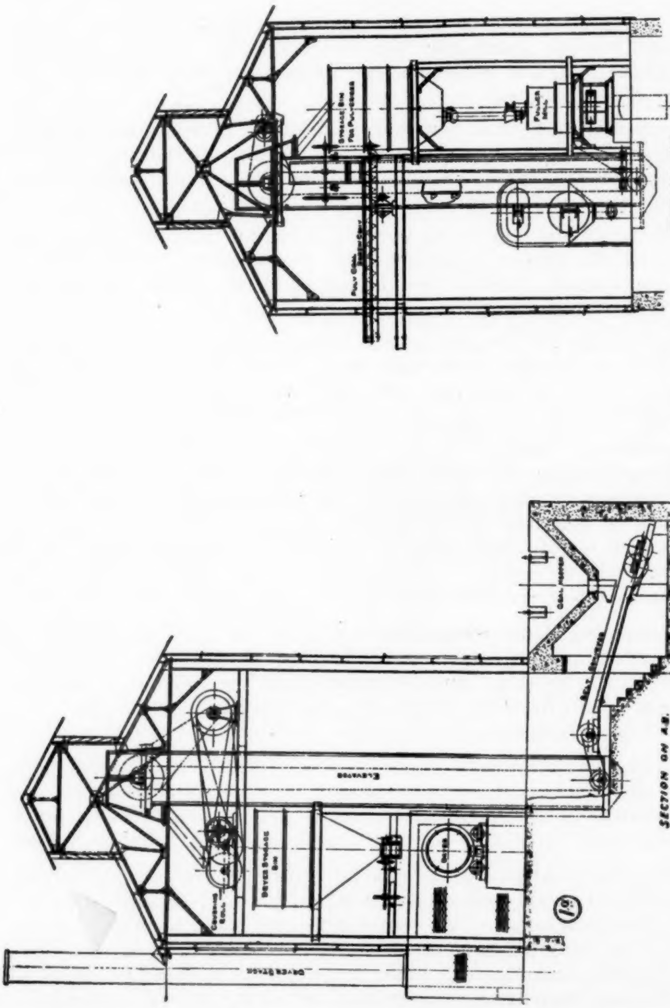

FIG. 10-A. SECTIONS OF PULVERIZING PLANT SHOWN IN FIG. 10.

A satisfactory coal would show an analysis about as follows:

Volatile matter	33 to 35	per cent
Fixed carbon	54 to 58	" "
Ash (high melting)	6 to 12	" "
Sulphur	1 to 1½	" "
Moisture	1 to 2	" "
Calorific value	14,000 B.t.u	

It is important that complete combustion shall take place in the shortest possible space after the fuel enters the furnace, and that it shall be complete before the hot gases come in contact with the material to be heated.

Such immediate and complete combustion prevents any sulphur from going into the furnace charge, by burning all of it into sulphur dioxide (SO_2), which passes out of the furnace with other waste gases.

All theory and experience unite in indicating that pulverized coal will give the highest attainable solid fuel efficiency, because all of the combustibles (100 per cent) going into the furnace are burned, and burned under practically perfect conditions.

Due to the fact that all of the heating value of the fuel is developed, considerable economies have become manifest by the use of pulverized coal over those attainable with raw coal firing or gas producers. These savings may be enumerated as follows:

In continuous furnaces for heating billets	25%	saved
In open-hearth producer-gas fired furnaces	30% to 35%	"
In puddling furnaces, unimproved furnaces	33% to 50%	"
In heating and busheling furnaces	20% to 25%	"
In cement nodulizing furnaces	20% to 25%	"
In steam boilers—hand fired	30% to 40%	"
In steam boilers—stoker fired	10% to 15%	"

Theoretical flame temperature of a fuel is the temperature to which the gases of combustion would be raised if just enough air were used to produce complete combustion, and if none of the heat were absorbed by other objects. Computations show that the theoretical flame temperatures of various fuels are as follows:

Natural gas	3,277 deg. fahr.
Fuel oil	3,441 deg. fahr.
Fairmont coal	3,558 deg. fahr.
Illinois coal	3,459 deg. fahr.

Powdered coal and its method of utilization embodies all of the essentials of good combustion in a high degree. Not only does complete oxidation of all of the combustible take place, but there is complete control of the amount of combustible and air used, the character of the flame, and the flame length; there is great flexibility in combustion capacity, and control of the nature of the combustion; finally combustion is essentially one stage.

There are four essentials to the complete combustion of powdered coal, as follows:

1. Fineness of pulverization;
2. Intimate mixture of dust and air;
3. Velocity of delivery of dust air mixture;
4. Temperature of combustion chamber.

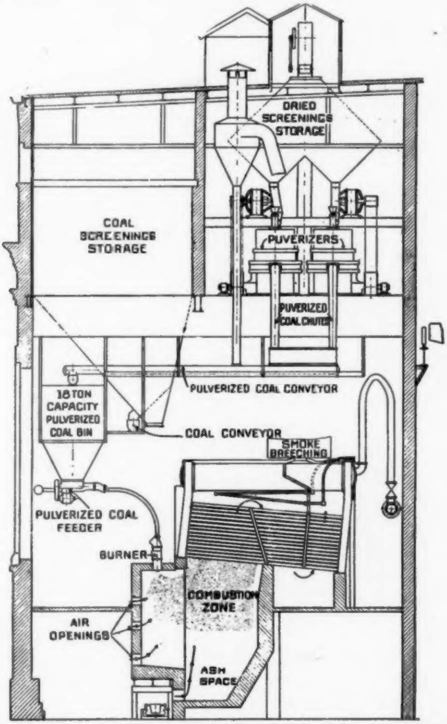

FIG. 10-B. POWER PLANT ARRANGED TO BURN PULVERIZED COAL.

The importance of intimately mixing the pulverized coal and air cannot be too strenuously insisted upon as the rapidity of combustion is a direct measure of the intimacy of mixture. The poorer the mixture the longer the flame; the time element of combustion is a function of the intimacy of the mixture, and the utmost obtainable rapidity of combustion is what is desired.

The rapidity of combustion not only depends on the fineness of the particles of coal, its intimacy of mixture with the air and the velocity of the flow of the mixed dust and air, but also depends on the temperature of the combustion chamber; consequently it is necessary that the temperature of the combustion chamber shall be

maintained at such a point that combustion is practically complete before the products of combustion pass over the heat absorbing surfaces.

In addition to the proper mixture of the powdered fuel and the air, the mechanism of combustion, the design of the dust-air injecting apparatus and the proportions of the combustion chamber are of great importance; particularly so, the combustion chamber, for unless this is properly designed and proportioned, no matter how perfect the dust-air mixture, the results will not be satisfactory.

There is a limit to the amount of pulverized coal which can be burned in a furnace of a given volume, therefore the combustion chamber must be proportioned to suit the maximum quantity of fuel to be burned in a given period of time.

ADVANTAGES OF PULVERIZING COAL AS A FUEL

1. Low grade and low cost coal can be used;
2. Complete combustion of fuel to CO_2, eliminating fuel loss in ash;
3. High efficiency of operation;
4. Great economy of operation, small number of operators required;
5. High temperature attained.[1]
6. Saving of fuel due to small amount of excess air required, reducing stack losses;
7. Ease of fuel regulation;
8. Close temperature regulation in combustion chamber;
9. Quick pick up of load;
10. Smokeless combustion;
11. Increase in convenience and cleanliness;
12. Short smoke stacks;
13. Flexibility of operation, permitting quick adjustment to suit any condition of underload or overload;
14. Control of character of flame, oxidizing, reducing or neutral;
15. Quick shut off of fuel in case of accident;
16. Ability to burn coals of almost any grade in pulverized form, regardless of the percentage of ash.

DISADVANTAGES OF PULVERIZING COAL AS FUEL

1. Inability to apply it economically to small furnace or boiler installations, due to the present elaborate and costly systems of crushing, drying, pulverizing, distributing, and operating apparatus required, and to the consequent high cost of preparation except for large installations. The cost of preparation of powdered fuel, including cost of crushing, drying, pulverizing and distributing, cost of power required for operation, labor, upkeep, supplies and overhead charges, depends upon the quantity handled. With plants of a fairly large size this cost

[1] Theoretically, with the supply of such an amount of air as will give the oxygen for perfect combustion, a temperature of about 4,500 deg. fahr. is attainable, and by admitting excess air in varying amounts all temperatures from 4,500 deg. fahr. down to 2,500 deg. fahr. are attainable.

averages about 40 to 50 cts. per ton, and rapidly increases as the plant diminishes in size;

2. Inability to store powdered fuel. The storage of powdered coal in large or small quantities for any length of time is to be avoided on account of its hygroscopic condition, its tendency to spontaneous combustion and to pack;
   a. Powdered coal in storage, containing about 0.75 per cent moisture and 1 per cent sulphur will invariably fire within a few days. If the moisture be increased to over 1 per cent and the sulphur to 4 or 5 per cent, spontaneous combustion may occur in 24 hours;
   b. Owing to the hygroscopic nature of dried pulverized coal, long storage is not desirable. In its normal state powdered coal is light and fluffy; after standing in storage for two or three days, the physical arrangement of the particles is changed and produces a dense packed mass. So dense does the fuel become that one's fingers cannot make an impression even to ½ in. in depth;
   c. To satisfactorily meet the conditions of distribution and feeding required by present pulverized coal practice, the coal must be dry and should be kept in motion;
3. Difficulty with present systems of operation of maintaining a homogeneous mixture of fuel dust and air, and of maintaining uniform feeding and a steady ignition during the entire period of operation;
4. Excessive formation of slag and ashes. One of the disturbing factors in the use of powdered coal is the tendency to the excessive formation of slag and ash when low grade fuels or fuels with an ash of low melting point are used. Just as much ash is formed with lump coal as with powdered coal, but the ash from pulverized coal is very fine and there is a tendency for a large amount of this ash to accumulate within the furnace and on the boiler tubes, only a small percentage escaping through the stack. When using even a good grade of coal, ash will accumulate and therefore, a coal of low ash content is always desirable. Where the ash is promptly removed the tendency to slag or cake is minimized.
5. Tendency to fusion and abrasion of fire brick lining of combustion chamber, due to the high temperatures attained, the blow pipe action of the flame of combustion, and the difficulty of finding economical materials to withstand these conditions. The effects of the pulverized coal flame on the brick work of the furnace are not worse than those from similar heat from grate coal or from oil firing; they are minimized with short flame firing and the attendant low velocities. This tendency is largely overcome by using as few burners to a furnace as possible, introducing the fuel into the furnace as far from the side walls as possible, and at as low an initial velocity as is consistent with attainment of instant and complete combustion, in the shortest possible time.

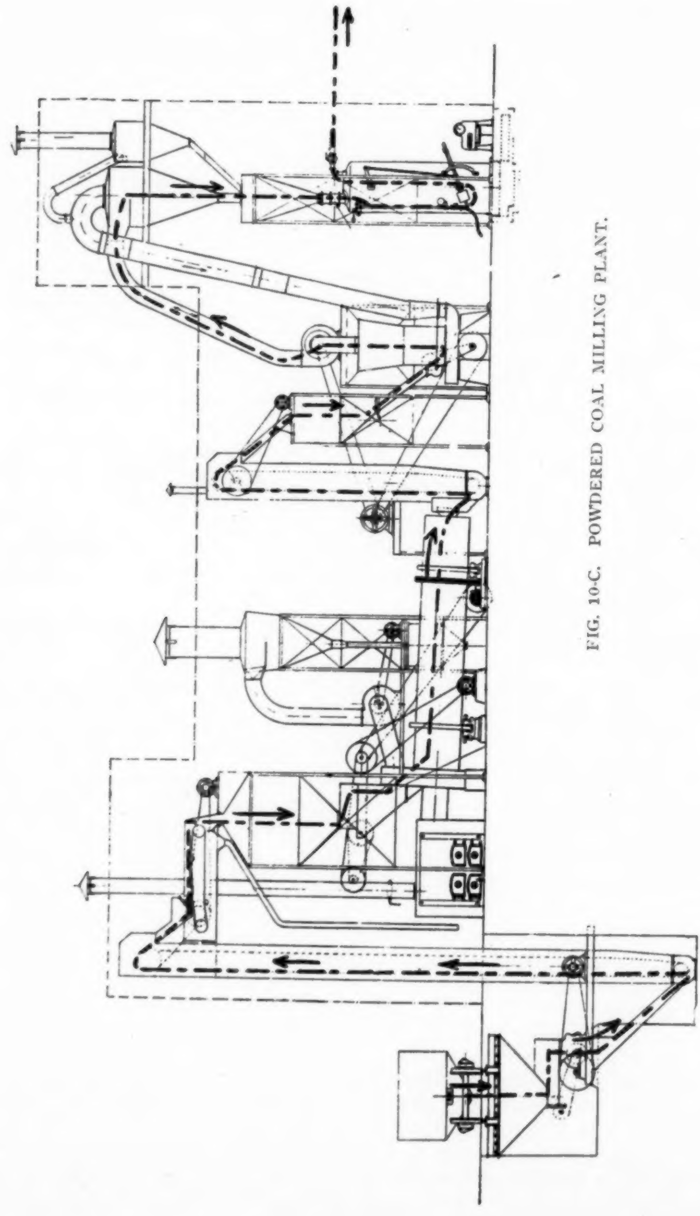

FIG. 10-C. POWDERED COAL MILLING PLANT.

6. Possibility of explosions. Coal dust, the same as other finely divided carbonaceous materials, is only dangerous when in a suspended state; that is, when surrounded by sufficient air to cause instant deflagration. When confined in a mass in a bin or tube there is very little chance for sufficient air to become thoroughly mixed with the dust to make an explosive mixture. With proper precautions, there is very little danger of exploding powdered coal; the explosion occurs only as a "puff" which is of very little consequence.

Success in the burning of pulverized coal *with present systems of operation* depends on the strict fulfillment of four main requirements:

1. The coal must be dried so that it contains not over 1 per cent of moisture, not that it cannot be economically burned with a certain amount of contained moisture, but because it cannot, when moist, be readily pulverized by ball or roll mills or passed through the distribution pipes or conveyors without danger of packing and clogging the pipes, bends and valves and so interfering with the uniform and continuous operation of the combustion apparatus. The difference between 1 per cent moisture and 5 per cent moisture in the pulverized coal will be about 50 B.t.u. per lb. of 12,500 B.t.u. coal, a mere trifle when compared with the cost of drying the coal to 1 per cent or less.
2. The coal must be pulverized to such a degree of fineness that not less than 85 per cent will pass through a No. 200 mesh screen and not less than 95 per cent through a No. 100 mesh; the finer the degree of pulverization, the more readily will the coal ignite, and the more nearly will it assume the condition of an approximate gas, when thoroughly mixed with air.
3. The coal must be projected into a chamber hot enough to cause instant deflagration.
4. The coal must be supplied with air sufficient to yield the oxygen necessary to burn the carbon of the coal at once to CO_2.

As at present applied a pulverized coal system consists generally of:

a. A crushing apparatus to reduce the lumps;
b. A magnetic separating apparatus to remove any tramp iron;
c. A drying apparatus;
d. A pulverizing apparatus;
e. A feeding injecting apparatus;
f. Elevating and conveying apparatus;
g. Storage bins, from which the coal is passed to the burners;
h. Compressed air or air blast apparatus, for mixing the proper amount of air for combustion with the powdered coal, and projecting it into the furnace.

The general operation of such a system is as follows: The coal is first carried by suitable mechanism to the crushing rolls where it is crushed to a size that will pass through the magnetic separator

which extracts all bits of scrap iron from the coal; from the magnetic separator it passes into the drier where its moisture content is reduced to 1 per cent or less; the coal then passes to the pulverizer where it is reduced to the required fineness (85 per cent through a No. 200 mesh screen); from the pulverizer it passes to the service coal bin; from the service bin it is delivered by suitable mechanism, to the injecting pipe, where it meets a volume of air delivered by suitable mechanism, with which air it is intimately mixed, and is then injected by the air blast into the furnace, where complete and instantaneous combustion takes place. When the system is in operation this cycle is continuous.

A typical form of a pulverizing and distributing system is shown in Figs. 10 and 10B; in which it will be seen, that the raw coal is received in a track hopper from the bottom of which it is discharged on to a belt or pan conveyor, and delivered to the boot of an elevator or to a pair of crushing rolls, in case run-of-mine coal is used.

The elevator raises the coal and discharges it into a bin located above the feed end of a rotary dryer; in passing through the dryer the moisture is removed, and the coal is discharged into an elevator, which raises and discharges it dried and crushed, into a storage bin above the pulverizing mill. From this bin, it is fed through a spout into the feed hopper of the pulverizer, in which it is reduced to the required degree of fineness.

The powdered coal is then discharged into an elevator, which delivers it to an overhead conveyor, which in turn delivers it to the individual furnace bins.

These pulverized coal bins, Fig. 17, which are located at each furnace, have a capacity proportional to the service required and hold a supply of pulverized coal in excess of the amount required during the intervals when the grinding is suspended. The bins are dust proof, and are of such a design that no trouble will be experienced from the pulverized coal becoming caked or "hanging up" on its way through the bin to the feeding device.

There are two systems used at the present time for conveying pulverized coal to the feeder bins located at the furnaces. One system conveys the coal pneumatically through a distributing system of pipes to the feeder bins. The other system, the one most in use, conveys the coal by screw conveyors, enclosed in dust tight troughs.

There are a number of devices in use for feeding the coal from the bins to the injectors or burners. A typical form, in general use, is shown in Figs. 13 and 14. It is essential that the feed of the pulverized coal to the burner should be under control of the furnace operator at all times. If the feed is not regular and positive, the efficiency of combustion will be materially lowered, and puffing at the furnace, or even extinction of the flame may take place.

The coal feeder shown in Fig. 14 is provided with a long screw conveyor enclosed in a housing. The coal enters the feeder from the storage bin through a hopper attached at the bottom of the bin. It fills the hopper and surrounds the feed screw which carries the coal to the feed pipe of the burner. The speed of rotation of the feed

screw is made variable, so that the quantity of coal fed to the burner may be controlled as required.

There are a number of forms of injectors, or so-called burners, see Fig. 13, in use for mixing the proper amount of air with the pulverized coal and injecting the mixture into the furnace; a typical one being shown in Fig. 14 and 14a. The pulverized coal drops from the conveyor hopper through the feed pipe, A, into the burner. Air from a fan, or compressor enters the burner through pipe B, mixes with the coal, draws the mixture of coal and air through the burner and injects it into the furnace. Additional air, which may be required for combustion, is introduced at E.

This method of pulverizing the coal is the one which, with modifications, is in general use at the present time, and is described at length to show how complicated it is, how much mechanism is involved, and to indicate how its cost militates against its general use except for very large installations.

It should be understood that the first cost of the fuel used is not the correct index by which to judge of economy when fuel must be prepared and pulverized.

Low grade bituminous coals, being high in non-combustible content, cause a very high pulverization cost, as compared to high-grade bituminous coals.

Equally, anthracite coals of high first cost, not only add to the pulverization cost on account of their hardness, but, notwithstanding the small non-combustible content, their economy in actual use is not to be compared to that of the best bituminous coals, because of their high fixed carbon content, resulting in much slower and uncertain ignition.

Slack coal is preferable to other forms; it costs less, requires less power for pulverization owing to its fine state, and materially increases the capacity of the pulverizer.

It has already been stated that pulverized coal must be properly prepared and applied as there is a sharp line of demarcation between the fuel itself and its method of preparation, and its method of application and combustion. No matter how, or by what means, it is prepared, all solid fuel pulverized to the same degree of fineness will burn equally well when similarly applied in a combustion chamber, but it is possible to have the pulverized fuel prepared by so costly a plant and in so expensive a manner that its general use would be prohibitory except in very large installations, and it is equally possible to have a low cost fuel applied in such an expensive or faulty form of combustion chamber that its use would not increase the efficiency or reduce the cost of operation sufficiently to warrant its use.

Both the method of preparation and of application must therefore be given careful consideration, each independently of the other, in order to arrive at the least expensive and most efficient method of their combined utilization.

For the proper combustion of pulverized coal in boiler furnaces, there are several main points which must receive serious considera-

tion in order to make the burning of this fuel a success; they are:

1. Coal fineness;
2. Capacity and design of combustion chamber;
3. Necessary air supply;
4. Proper damper regulation;
5. Clean tubes;
6. Removal of ash deposited at the bottom of the combustion chamber.

The finer the coal is pulverized, the more complete will be the combustion. The pulverized coal should run about 95 per cent through a 100 mesh screen, and about 85 per cent through a 200 mesh screen. If it runs below 80 per cent through a 200 mesh screen, particles of coal will pass through the combustion chamber in a partly consumed condition and will reach the boiler tubes before

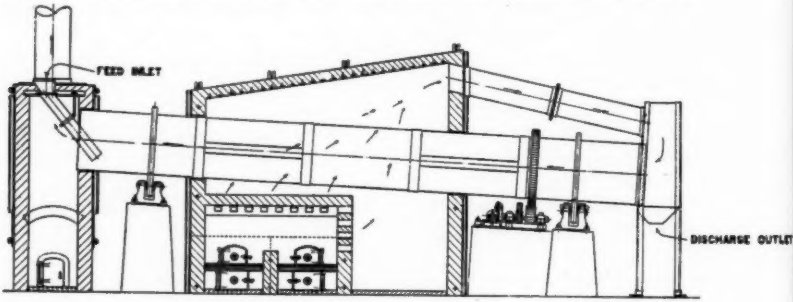

FIG. 11. COAL DRYING APPARATUS.

complete combustion takes place, and be deposited thereon, where they will slowly consume to the detriment of the tubes, reducing the heat absorption by the tubes and causing the formation of a coating of slag, which will accumulate and be difficult to remove.

In addition, some of these heavy particles will settle to the bottom of the combustion chamber and build up until the mass comes in contact with the flame of combustion when they will fuse into a solid mass, necessitating a shut down of the boiler to dig this fused mass out. It is, therefore, necessary to have the coal as finely pulverized as possible in order to obviate these difficulties.

The capacity and design of the combustion chamber is of the first importance, as on its proper arrangement depends the ability to burn the necessary amount of fuel required for the full boiler capacity operation. The maximum boiler rating must first be decided upon and the combustion chamber designed accordingly.

If the boiler should be operated under this maximum rating, the boiler efficiency will not be perceptibly decreased, but if it is attempted to operate the boiler over this maximum rating, more coal and air will have to be admitted to develop this higher rating; consequently, more combustion space is required, but not having it, the flames are apt to impinge on the brick work and rapidly erode

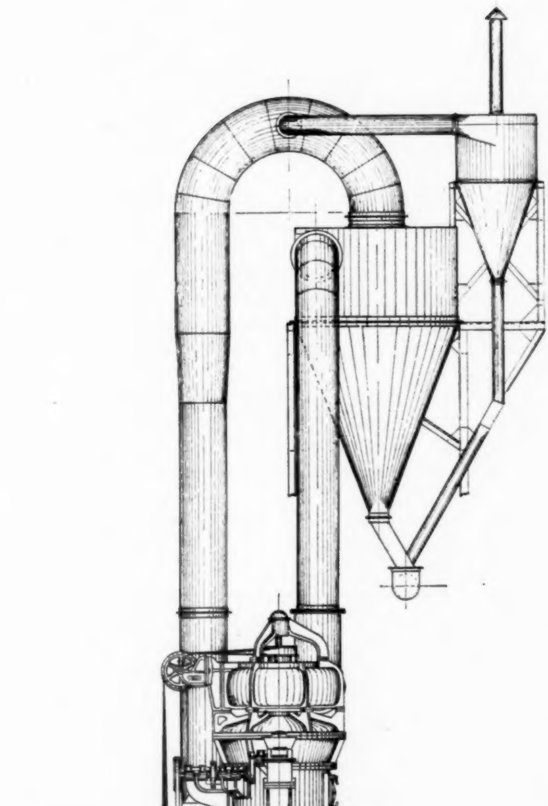

FIG. 12. PULVERIZING MILL.

it. In addition, the combustion not being complete before the gases strike the bottom row of tubes, the difficulty before stated will take place and the boiler efficiency will be reduced.

The size of the combustion chamber should also be so designed that the velocity of the gases passing through the combustion chamber may be reduced to as low a speed as possible and yet keep the pulverized fuel in suspension. The mixture of air and coal should also be introduced into the combustion chamber at a very low pressure—just breathed in. Provision should be made, by means of which additional air for combustion can be admitted to the furnace if required.

In order to control the velocities of the gases passing through the combustion chamber, very accurate damper regulation should be provided, and it should be so regulated that there is practically a balanced draft inside the combustion chamber and only a slight vacuum at the first pass, while at the damper itself only 0.10 to 0.15 in. should obtain. The nearer these balanced conditions can be maintained, the more perfect will be the combustion, and the higher the efficiency attained.

In order to get the maximum evaporation from any boiler it is of prime necessity that the tubes be kept clean, both inside and outside. The keeping of the tubes clean inside is a question of the proper quality of water and, of course, has nothing to do with the question of pulverized coal.

The keeping clean of the outside of the tubes is very necessary with the use of pulverized coal as a fuel, and all steam boilers should be equipped with a standard type of soot and ash removing device or blower, one which can be operated without interfering with the operation of the boiler. The soot blower should be used as frequently as is necessary to keep the tubes clean and fully receptive of the heat from the gases of combustion. Also, at least once every 24 hours, the bottom of the first row of tubes should be blown off, these being the tubes with which the gases first come in contact after leaving the combustion chamber. This material can be blown off easily if blown regularly, but if allowed to accumulate, in time it will become fused and cannot be blown off.

The removal of the ash which deposits at the bottom of the combustion chamber should be attended to at frequent intervals, determined by the amount of ash in the original coal. If not removed regularly, it will build up until it approaches the flame, when it will become fused and will have to be dug out, while if regularly removed, it can be easily raked out and will not interfere with the operation of the boiler while this is being done.

Next in importance to correct furnace design and properly controlled draft, is the coal feeding mechanism, for on its successful operation the success of the boiler largely depends.

It is an axiom that the simpler a mechanism is, to obtain a desired result, the better and more efficient will be its operation. So as regards the coal feeding and burning mechanism, the simpler it is,

the fewer its parts consistent with the attainment of the desired combustion results, the more satisfactory will be those results.

Theory and experience unite in indicating that pulverized coal will give the highest attainable solid fuel efficiency, because all of the carbon—100 per cent—entering into the combustion chamber, is burned under practically perfect conditions, so that combustion is complete and smokeless. By its use a maximum of fuel can be consumed and boiler ratings of 200, 300, and even higher per cent can be readily attained.

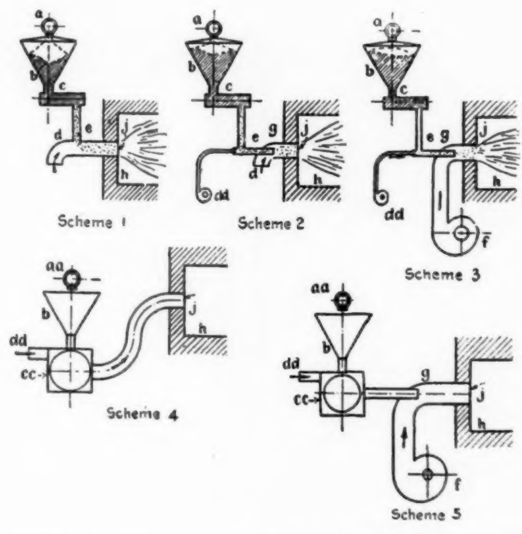

FIG. 13. VARIOUS FORMS OF PULVERIZED COAL FEEDING MECHANISM.

In addition to complete, smokeless combustion, high boiler rating and consequently high boiler efficiency, there are many other advantages gained by the use of pulverized coal.

There is extreme simplicity of combustion chamber construction and coal feeding mechanism, with consequent flexibility of operation, ease of fuel control and regulation, permitting quick adjustment to suit any condition of underload or overload, quick pick-up of load and close temperature regulation in the combustion chamber.

No banking of fires is required as the fuel supply can be instantly shut off or turned on and ignited as may be required, in putting a boiler out of, or into operation, or in case of accident.

Low grade coals can be used regardless of the percentage of ash, and great economy of operation attained due to the small number of operators required.

There is also increased convenience and cleanliness of operation, less chance for derangement, accident or breakdown, and greatly diminished wear, tear and consequent repairs.

Its many desirable features merit careful consideration when deciding upon the fuel system which shall be utilized in a boiler plant. It solves the fuel problem for the vast majority of boilers now operating uneconomically, all of which, however, by the proper use of pulverized coal, can be brought to the highest state of efficiency.

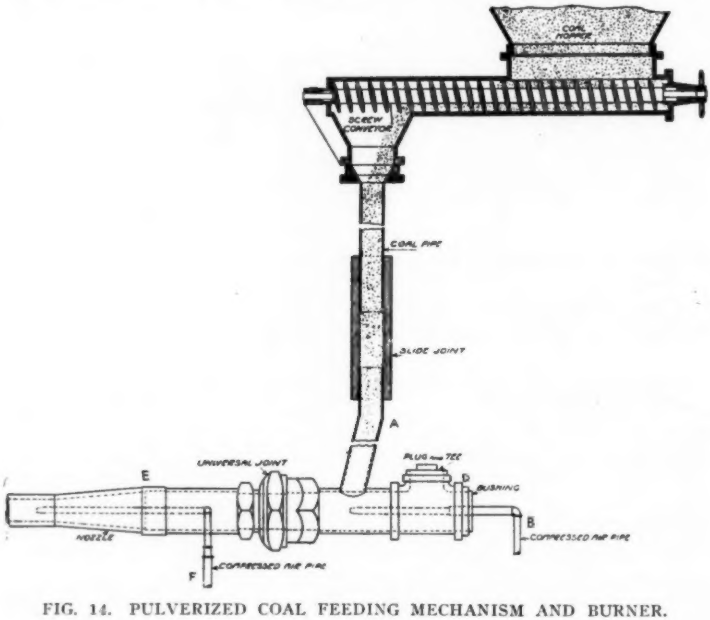

FIG. 14. PULVERIZED COAL FEEDING MECHANISM AND BURNER.

Not less than 85 to 90 per cent of all of the combustion furnaces and steam boiler plants in commercial use are small in size, the steam boiler plants ranging from 100 h. p. to 500 h. p. in capacity and having an efficiency of fuel conversion of not to exceed 40 to 50 per cent. There are thousands of such plants, all of which need radical improvement and all of which can utilize pulverized fuel to the utmost advantage, provided its cost of preparation and method of utilization can be reduced to such a point as not to be so excessive as to render its use prohibitory.

The present methods of pulverized coal preparation are too complex, require too much machinery and are too costly for use in any but the very large plants, and are quite out of the question for the great majority of the small plants.

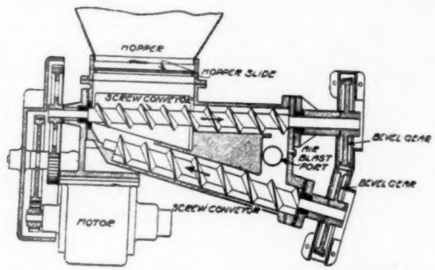

FIG. 14-A. PULVERIZED COAL FEEDING MECHANISM.

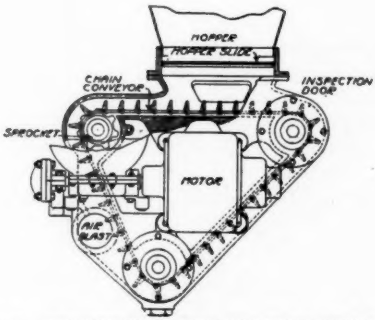

FIG. 14-B. PULVERIZED COAL FEEDING MECHANISM.

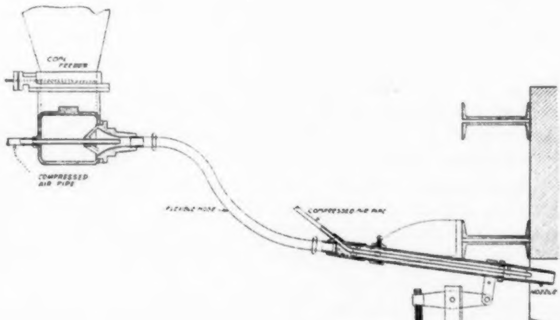

FIG. 14-C. PULVERIZED COAL FEEDING MECHANISM AND BURNER.

Table 1, taken from a paper[1] on Pulverized Coal as a Fuel, by Mr. N. C. Harrison, gives a statement of the approximate cost of pulverizing plants such as are installed by three of the leading pulverized coal companies and the cost per ton of coal pulverization.

These figures cover the pulverizing plants and containing buildings, for installations of from 10 to 250 tons of coal daily, and include all costs except interest and depreciation in the pulverizing plant proper. To these costs must be added the cost of the conveying machinery from the pulverizing plant to the storage bins at the combustion chambers, the storage bins and apparatus for feeding the coal into the furnaces and providing the necessary amount of air for its combustion, which costs are indeterminate, depending in each case on the position of the pulverizing plant, the position of the combustion plant, and the distance which the pulverized coal has to be conveyed.

From this table it appears that the estimated cost of the pulverizing plant, including buildings, for so small a boiler installation as 250 h. p. is about $31,000, ranging up to $62,000 for a 6,000 h. p. installation. To this must be added the cost of the mechanism required for delivering the pulverized coal to the storage bins at the combustion chambers, the storage bins, the compressed air and fan apparatus, the pulverized coal-feeding apparatus, the tuyeres or burners for delivering the pulverized coal to and into the combustion chamber, and the motive power for operating these mechanisms, all of which will add a very considerable amount to the cost of the pulverizing plant, so that the total cost of the pulverized coal equipment will not be far from $45,000 for the 250 h. p. plant to $90,000 for the 6,000 h. p. plant. The cost of pulverizing the coal is also excessive, estimated at from 56 cts. per ton for a 250 h. p. plant to 30 cts. per ton for a 6,000 h. p. plant.

From this it will readily be seen that such a complex and costly system for pulverizing and applying the coal to the combustion chamber limits its use to such plants as, by reason of their size, can stand the large initial cost of the pulverizing plant.

This may be all right for the "big fellows" but what about the 85 to 90 per cent of the "little fellows," those with small and inefficient furnace or boiler plants? Where do they come in?

To render the use of pulverized coal as universal as possible, some much simpler and less expensive method of coal pulverization and its application is required, and must be developed, else its use will always be limited and the great benefits to be derived from its use will not be realized.

The solution of the problem lies in the simplification of the present methods of application of pulverized coal; the elimination of the large and costly installations now required to convert the coal into pulverized form; and the devising of such means of application as will enable the small plant, the "little fellow" to apply and utilize pulverized coal in a comparatively inexpensive manner.

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[1] Published in the Journal of *The American Society of Mechanical Engineers*, August, 1919, page 645.

When that is accomplished, the utilization of this type of fuel will go forward with leaps and bounds and the time will surely and quickly come, when it will be a matter of wonderment that such a crude method as burning coal in the lump form, continued in use so long; the fuel conservation showing will be so great as almost to stagger belief.

A system for the successful application of pulverized coal as a fuel to the small plants, say under 1,000 h. p. capacity, should be

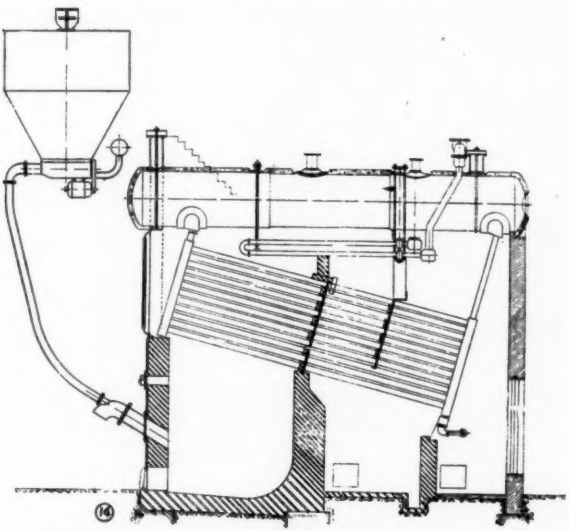

FIG. 15. PULVERIZED COAL BIN, FEEDING MECHANISM AND BURNER APPLIED TO STEAM BOILER.

simple, compact, easily adapted to the combustion apparatus, easily controlled and repaired, requiring only such changes in the furnace equipment as can be made with the least possible interference with its regular operation, and one whose cost of installation and operation is a minimum; in fact, a *unit* machine, which can be applied singly to each furnace, and which involves no costly and complicated crushing, drying, pulverizing and distributing apparatus, but is self-contained, performing all necessary functions within and by itself.

Such a *unit* system is possible and has been successfully worked out in at least one instance and satisfactorily demonstrated through a considerable period of utilization; particularly in connection with clinkering kilns for cement manufacture. Apparently very little attention has been given to the great value of such a method of pulverized coal utilization, combining as it does in one machine all of the requirements, as already stated, of a universal system of pulverized coal application.

The underlying principle involved in this type of pulverized coal apparatus is, that all of the required operations involved in the preparation of the lump coal into pulverized form are performed in and by a single, or *unit*, apparatus; the commercial undried lump coal after being crushed to a uniform size, if necessary, is fed into the hopper of the machine in which it is ground, pulverized, mixed

TABLE 1. COST OF COAL-PULVERIZING PLANTS AND COST OF PULVERIZING COAL PER TON NET

Tons daily	Total cost of pulverizing per ton, dollars	Cost of plant including building, dollars	Labor, hours	Labor, cost per ton, dollars
10	0.56	31,000	10	0.30
20	0.51	31,000	20	0.25
30	0.49	31,000	30	0.23
40	0.49	31,000	40	0.23
50	0.39	37,000	26	0.13
60	0.39	37,000	30	0.13
70	0.39	37,000	40	0.13
80	0.39	37,000	40	0.13
90	0.39	37,000	46	0.13
100	0.34	45,000	34	0.09
110	0.34	45,000	37	0.09
120	0.33	45,000	40	0.08
130	0.33	45,000	44	0.08
140	0.32	50,000	45	0.06
150	0.32	50,000	47	0.06
160	0.32	50,000	50	0.06
170	0.32	50,000	54	0.06
180	0.32	50,000	57	0.06
190	0.30	62,000	48	0.04
200	0.30	62,000	51	0.04
210	0.30	62,000	53	0.04
220	0.30	62,000	56	0.04
230	0.30	62,000	59	0.04
240	0.30	62,000	61	0.04
250	0.30	62,000	63	0.04

Labor rate: Millers, 30 cents per hr.; drier firemen, 20 cents per hr.; common labor, 20 cents.

Cost of drier fuel: 6 cents per net ton, based on 7 per cent moisture. Coal at $5 per ton delivered.

Evaporation: 6 lb. per lb. of coal burned or 26 lb. of coal per ton.

Repairs: 7 cents per net ton. This includes whole pulverizing plant, all machinery.

Power has been based on 12.7 cents per ton pulverized, and a consumption of 17 h.p.-hr. per ton pulverized at 1 cent per k.w.-hr. or about $54 per h.p. per annum.

with the required amount of air and by it injected into the combustion furnace.

Early experiments prior to 1867 along this line were made by Anthony M. Robeson and Claude Bettington at the Rand Mines in South Africa; afterwards continued by O. S. Newcomb at the Duane Street plant of the New York Edison Co. in New York and concluded at the works of Fraser & Chalmers, England, (see Fig. 19.)

In 1867-1868, a *unit* apparatus, devised by Whelpley & Storer was tested at South Boston, Mass.

In 1881, Palmer, and in 1897, Storer and Eaton, devised and patented such a *unit* type apparatus. In 1910, a *unit* apparatus, devised by J. E. Blake, was tested at the Henry Phipps power plant, Pittsburgh, Pa.,—see Fig. 20.

In 1914, a later form of the Blake apparatus was installed at the Peter Doelger Brewery, New York City.

All of these tests and trials were, like most new things, more or less crude and experimental in character, but all gave promise and pointed the way to betterment.

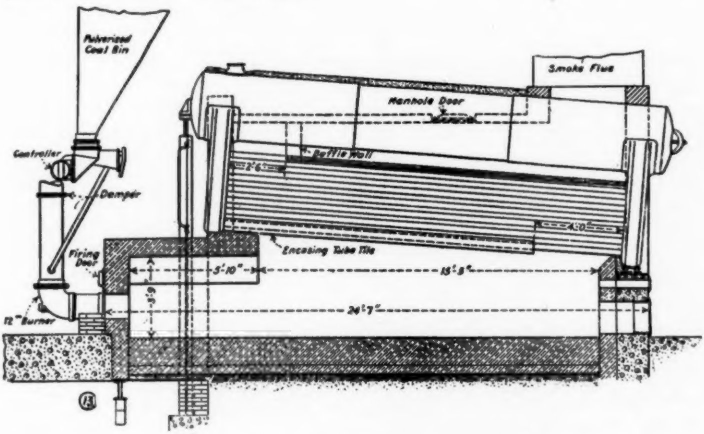

FIG. 16. PULVERIZED COAL BIN, FEEDING MECHANISM AND BURNER APPLIED TO STEAM BOILER.

In 1912 this subject was taken up by the Aero Pulverizer Co. of New York, and by them improved and perfected until at the present time their *unit* apparatus is in successful operation in the cement and metallurgical industries, fulfilling in all respects the requirements of a universal system of pulverized coal utilization.

As shown in Figs. 21, 21A and 22, the *unit* pulverizer consists of a closed cylindrical shell, divided by partitions into several, in this case four, interiorly communicating chambers of successively increasing diameters in which revolve paddles or beaters, on arms of correspondingly increasing lengths; each chamber is in fact a separate pulverizer; each succeeding pulverizer having a greater diameter and consequently a greater peripheral speed and greater power for fine grinding; each receiving and treating the product of the preceding chamber and passing it on to the next succeeding chamber for still further reduction. An additional chamber contains a fan, which acts to draw the finely pulverized material successively from one chamber to the next, and finally to deliver it

through a pipe and inject it into the furnace under the impetus of a forced draft.

A regulable feed mechanism feeds the lump coal, crushed if necessary to a suitable size, from the hopper into the pulverizer, controls and at the will of the operator varies the quantity of coal admitted to and delivered by the machine.

Auxiliary, regulable inlets in the feed mechanism admit the air required for fine grinding, and a regulable auxiliary inlet between the last pulverizing chamber and the fan admits such additional air as is required for combustion. The combined air inlets and feed mechanism give complete regulation of the length and temperature of the flame and its chemical conditions within a wide range.

This form of pulverizer is simple in design and construction; is compact in form, taking up a minimum of floor space; is easily applied to the combustion apparatus, each pulverizer being designed to operate as a *unit* with a single furnace; is easily repaired; is under complete control both as to air and coal admission, and the character of the flame produced. The air mixing operation commences at the feed end of the pulverizer, where the coal and air enter together, and pulverizing and air mixing progress as one operation. Additional air can be admitted through a regulable inlet, so that the mixture of coal and air is made complete and homogeneous; thence it is blown through a suitable conduit and injected into the furnace. Means are provided for instant, easy and accurate regulation of the quantity of coal needed in the furnace and the amount of air required, furnishing resultant control over the temperature of the furnace and the quality of the products of combustion; it can be readily applied to the combustion apparatus and can be placed in any desired position relative to the same; it can be applied with the least amount of alteration in the combustion furnace and with a minimum of interference with the regular operation of the same; the cost of the apparatus and its installation is reduced to a minimum.

Artificial drying of the coal is not necessary if the supply be sheltered from rain and snow, and is not economical where the coal available contains less than 4 per cent of moisture.

So far as the drying of the coal is concerned, it is harmful in that, at the temperature required for drying, a considerable percentage of the volatiles in the coal are driven off, thus reducing its B. t. u. value; the total gain in per cent of moisture reduction is very small when account is taken of the moisture content of the air which is mixed with the powdered coal and used to inject it into the combustion chamber.

Thousands of tons of pulverized coal which have never passed through a dryer are satisfactorily burned every day in the year in all sorts of furnaces.

In this type of apparatus, the *unit*, there is no storage of powdered coal required; it is burned as produced and any hazard of fire or explosion is eliminated.

There are no dryers, dust conveyors, storage bins, mixing chambers, nor feeding mechanisms with the several power units required

to operate them; new buildings are not required. Manual labor is practically eliminated and one operator can attend to a number of pulverizers. In addition to the matter of the cost of the apparatus and its installation, the cost per ton of pulverized coal production is reduced to a practical and commercial minimum. It therefore appears that a pulverizing apparatus of the *unit* type makes practicable the highest efficiency obtainable from coal; causes it to burn like a gas; produces at will a wide range of temperatures; produces a flame, the physical and chemical characteristics of which are regu-

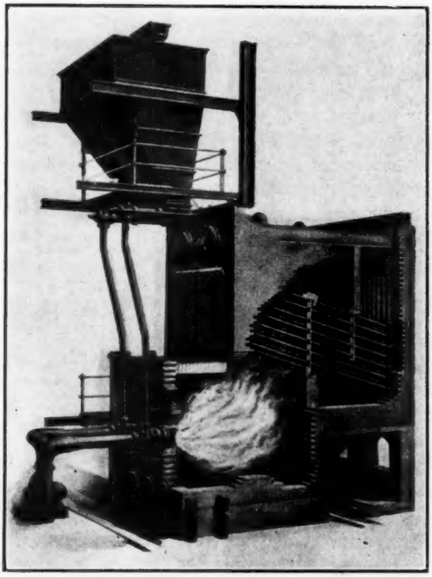

FIG. 17. PULVERIZED COAL APPLICATION TO TYPICAL WATER TUBE BOILER.

lable, one which may be elongated or shortened, made oxidizing, reducing or neutral as occasion may require, and is the nearest approach to a method which fills all the requirements, making possible the universal application of pulverized coal as a fuel to all industrial purposes.

Since powdered coal may be made to burn like a gas with a dazzling white flame and intense energy, without smoke, leaving no carbon in the ash, with flue gases approximating theoretical perfection, making easily attainable a temperature of approximately 3,500 deg. fahr. almost evenly distributed throughout the combustion chamber; with no opened doors or cold draughts, without banked fires; with the time required to heat a cold furnace reduced by more than half; with great economy in fuel and labor and with increased

through a pipe and inject it into the furnace under the impetus of a forced draft.

A regulable feed mechanism feeds the lump coal, crushed if necessary to a suitable size, from the hopper into the pulverizer, controls and at the will of the operator varies the quantity of coal admitted to and delivered by the machine.

Auxiliary, regulable inlets in the feed mechanism admit the air required for fine grinding, and a regulable auxiliary inlet between the last pulverizing chamber and the fan admits such additional air as is required for combustion. The combined air inlets and feed mechanism give complete regulation of the length and temperature of the flame and its chemical conditions within a wide range.

This form of pulverizer is simple in design and construction; is compact in form, taking up a minimum of floor space; is easily applied to the combustion apparatus, each pulverizer being designed to operate as a *unit* with a single furnace; is easily repaired; is under complete control both as to air and coal admission, and the character of the flame produced. The air mixing operation commences at the feed end of the pulverizer, where the coal and air enter together, and pulverizing and air mixing progress as one operation. Additional air can be admitted through a regulable inlet, so that the mixture of coal and air is made complete and homogeneous; thence it is blown through a suitable conduit and injected into the furnace. Means are provided for instant, easy and accurate regulation of the quantity of coal needed in the furnace and the amount of air required, furnishing resultant control over the temperature of the furnace and the quality of the products of combustion; it can be readily applied to the combustion apparatus and can be placed in any desired position relative to the same; it can be applied with the least amount of alteration in the combustion furnace and with a minimum of interference with the regular operation of the same; the cost of the apparatus and its installation is reduced to a minimum.

Artificial drying of the coal is not necessary if the supply be sheltered from rain and snow, and is not economical where the coal available contains less than 4 per cent of moisture.

So far as the drying of the coal is concerned, it is harmful in that, at the temperature required for drying, a considerable percentage of the volatiles in the coal are driven off, thus reducing its B. t. u. value; the total gain in per cent of moisture reduction is very small when account is taken of the moisture content of the air which is mixed with the powdered coal and used to inject it into the combustion chamber.

Thousands of tons of pulverized coal which have never passed through a dryer are satisfactorily burned every day in the year in all sorts of furnaces.

In this type of apparatus, the *unit,* there is no storage of powdered coal required; it is burned as produced and any hazard of fire or explosion is eliminated.

There are no dryers, dust conveyors, storage bins, mixing chambers, nor feeding mechanisms with the several power units required

to operate them; new buildings are not required. Manual labor is practically eliminated and one operator can attend to a number of pulverizers. In addition to the matter of the cost of the apparatus and its installation, the cost per ton of pulverized coal production is reduced to a practical and commercial minimum. It therefore appears that a pulverizing apparatus of the *unit* type makes practicable the highest efficiency obtainable from coal; causes it to burn like a gas; produces at will a wide range of temperatures; produces a flame, the physical and chemical characteristics of which are regu-

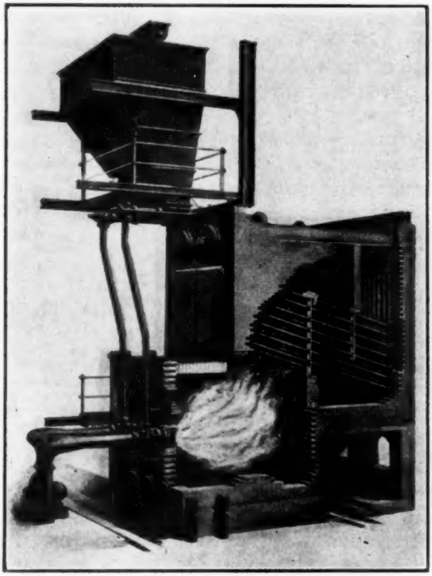

FIG. 17. PULVERIZED COAL APPLICATION TO TYPICAL WATER TUBE BOILER.

lable, one which may be elongated or shortened, made oxidizing, reducing or neutral as occasion may require, and is the nearest approach to a method which fills all the requirements, making possible the universal application of pulverized coal as a fuel to all industrial purposes.

Since powdered coal may be made to burn like a gas with a dazzling white flame and intense energy, without smoke, leaving no carbon in the ash, with flue gases approximating theoretical perfection, making easily attainable a temperature of approximately 3,500 deg. fahr. almost evenly distributed throughout the combustion chamber; with no opened doors or cold draughts, without banked fires; with the time required to heat a cold furnace reduced by more than half; with great economy in fuel and labor and with increased

capacity; with all under easy control of an operative of whom no back-aching duties are required; because pulverized coal has come into almost universal use as a fuel for clinkering cement and occupies a wide field for firing metallurgical and chemical furnaces, burning lime, calcining gypsum and operating dryers; because it has steadily advanced in a great variety of fields where the requirements call for constant temperature, high or low, variable temperatures in the same operation, and a variety in the quality of the products of combustion, such as reducing, neutral or oxidizing atmosphere; because for the dirty, disagreeable, exhausting human labor job of stoking, it substitutes a clean, agreeable, easy duty of supervision of mechanical equipment requiring short experience, simple instructions and no technical education; for these reasons and many more, it has become imperative that the use of powdered coal be extended to include the furnace of most general use, the one consuming more coal than all other industrial furnaces combined and which has no exact requirements as to temperature or quality of the products of combustion, namely, the furnace for generating steam.

In developing the application of pulverized coal to boiler furnaces, certain difficulties are encountered of which the principal ones are:

1. Maintaining prompt, continuous and steady ignition, with coal varying in quality and in moisture.
2. The destruction of the brick work under the high temperatures easily attainable with powdered coal.
3. The maintenance of a homogeneous mixture in all parts of the furnace until combustion is completed.
4. The tendency of the coarser particles of coal to fall out of the zone of combustion.
5. The handling of molten ash.

It is now common knowledge that in the successful use of pulverized coal, combustion must be carried on and completed before the gases come in contact with the water-cooled tubes of the boiler.

In the use of pulverized coal under boilers, its combustion in an atmosphere of high temperature is desirable because in such an atmosphere conditions are favorable to rapid, perfect and complete combustion before the gases reach the tubes. More steam is generated; the ash collected is liquid and will flow instead of deposit in sticky, unmanageable form; precipitated carbon will float and be burned; the percentage of heat lost up the stack will be reduced; the formation of CO under such conditions can only arise from deficient air, and the cheaper grades of coal may be used.

A further word as to the prevailing sentiment that coal must be dried to less than 1 per cent of moisture before using it in powdered form. There are thousands of tons of coal in powdered form being used daily that are being pulverized and fed directly to the furnace, without storage and without previous drying. Where the coal can be thus handled, pre-drying becomes a question of furnace economy only, and where a supply is available, carrying less than 3 per cent of moisture, the expense of installing and operating a dryer with the necessary elevating, storage and conveying apparatus cannot be

shown to be profitable even if the coal occasionally comes with considerably higher moisture.

The following explanation may serve to make the procedure in the furnace better understood. Segregate a cubic foot of the mixtures of coal and air. It would not be far afield to estimate that 1 cu. ft. of air carries about 1/12 oz. of coal, broken up into particles, some of which will pass a 400 mesh and nearly all of which

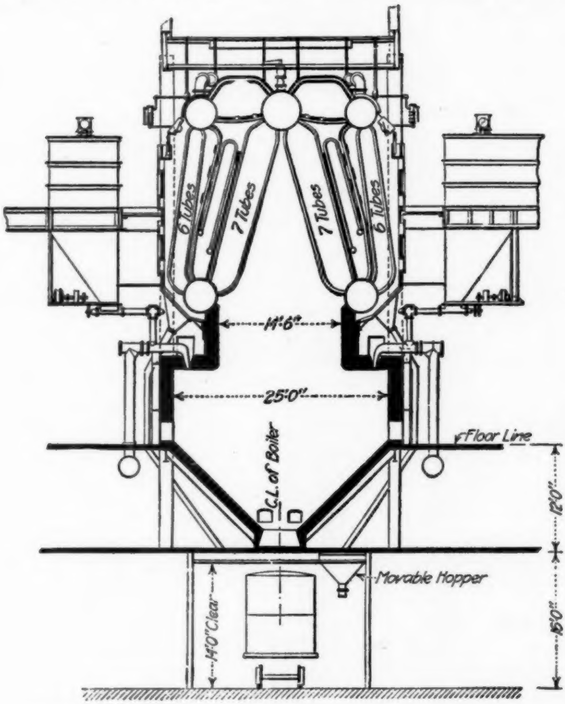

FIG. 18. PULVERIZED COAL APPLICATION TO EDISON TYPE BOILER WITH DOUBLE BURNERS.

will pass a 100 mesh, with intermediate grades. Probably 2,000,000 is a low estimate of the number of particles in the cubic foot of air, each particle of which is surrounded by the free oxygen of the air. Combustion begins, CO_2 rapidly displaces the free oxygen; the gases expand 5 to 10 times their original volume, according to the maximum temperature of the furnace; the finer particles disappear first, the coarse survive to the last, are few in number and widely separated in a diluted atmosphere, must find free oxygen and find it instantly or be swept unconsumed among the tubes and lost.

The question then is, what can powdered coal do in the boilers that are not fired from grates; can the furnace lining be protected;

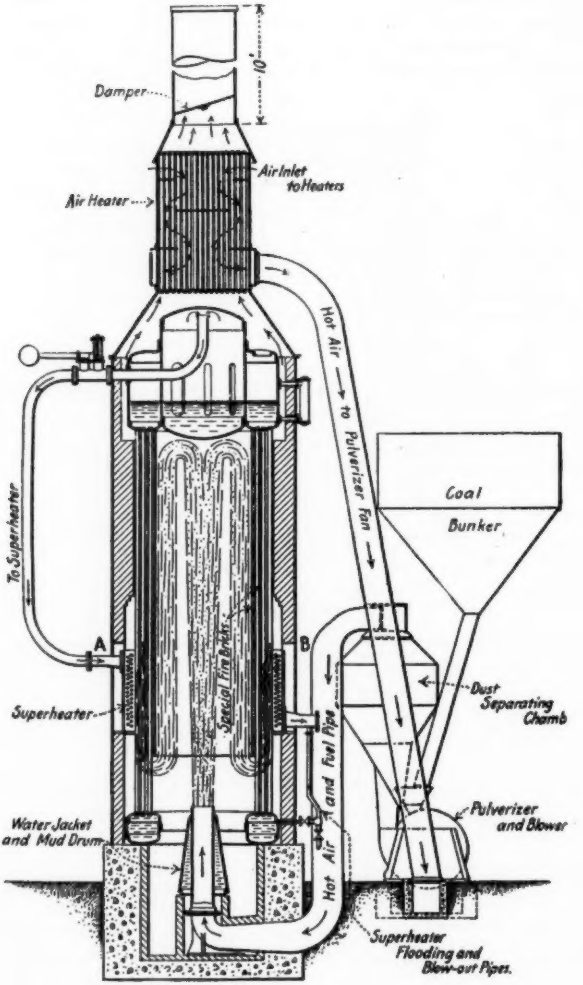

FIG. 19. BETTINGTON BOILER WITH PULVERIZED COAL UNIT APPLICATION.

can the liquid ash be easily disposed of; can the gases in the furnace be mixed as combustion progresses; can low-volatile and high moisture coal be used? All these points have to do with the inside of the furnace and not with the preparation or handling of the coal outside.

These problems have been studied by many acute minds and have been in a measure solved, the main effort being to so shape and enlarge the combustion chamber and so discharge the mixed coal and air into the combustion chamber, that complete combustion takes place within a short distance from the point of entry; that the gases of combustion have a long path of travel before they enter the boiler tubes; that the velocity of travel of the flame gases of combustion is reduced to as low a point as possible and that at their zone of most intense temperature they do not come into contact with the walls of the combustion chamber.

Furthermore, the direction of entrance of the mixed coal and air is such that all heavy particles, ash, etc., both before and after combustion drop out and fall to the bottom of the combustion chamber from which position they can readily be removed by suitable cleaning doors.

Such arrangements of the combustion chambers solve most of these difficulties to a greater or less degree with the exception of the complete protection of the fire brick lining, which under high overload temperatures, is apt to be melted or eroded, and also the reduction of the stack gas temperatures, which are apt to be high, due to the boiler tubes being unable to absorb the maximum part of the heat generated.

The main difficulty with the re-design and reconstruction of the combustion chamber is the high cost involved and the great loss of time due to the boiler being put out of commission during such reconstruction.

To overcome these difficulties and provide a combustion chamber which shall be simple, low in cost, easily and quickly installed and one in which no melting or erosion of the brickwork takes place and by means of which the maximum heat of combustion is absorbed by the boiler, attempts have been made to surround the combustion chamber with water tubes imbedded in the fire brick walls, which are properly connected to the water circulating system of the boiler and serve the double purpose of absorbing the heat of combustion, thereby increasing the steam generating capacity of the boiler and at the same time protecting the lining of the combustion chamber from melting and erosion by greatly reducing the temperature of the gases of combustion.

A most successful and satisfactory form of this type of combustion chamber and one which can be readily and economically applied to any standard type of steam boiler is the one devised by the Aero Pulverizer Company and shown in Fig. 23.

As shown, this combustion chamber is rectangular in shape and consists of a front and rear header, similar to those in use in the Heine and other water tube types of boilers, joined together by a series of water tubes which form the sides and bottom of an open box or cradle. These water tubes are enclosed in high temperature tiles similar to those used in boiler baffle plates.

The front and rear headers are suitably connected to the boiler water-circulating system and form part thereof.

By this arrangement combustion is carried on in an atmosphere of very high temperature, well above the fusing point of any ash and

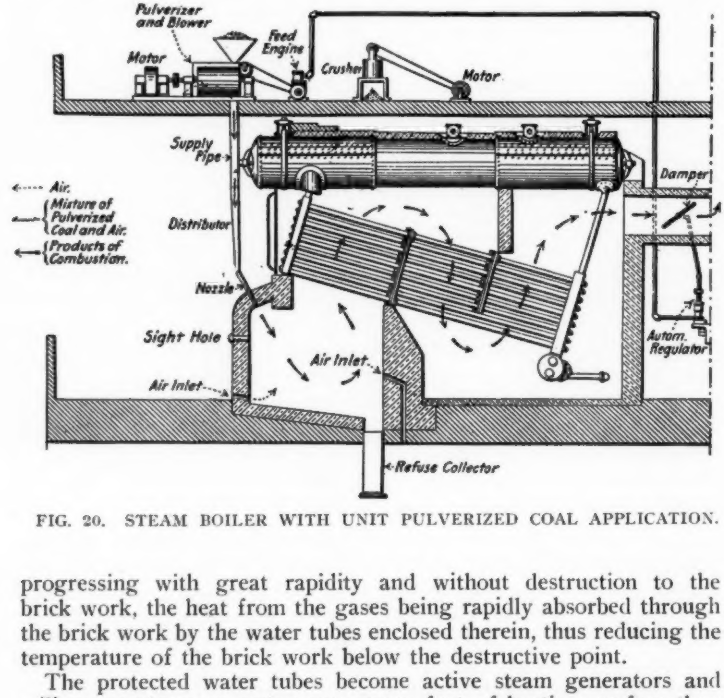

FIG. 20. STEAM BOILER WITH UNIT PULVERIZED COAL APPLICATION.

progressing with great rapidity and without destruction to the brick work, the heat from the gases being rapidly absorbed through the brick work by the water tubes enclosed therein, thus reducing the temperature of the brick work below the destructive point.

The protected water tubes become active steam generators and will evaporate more water per square foot of heating surface than the tubes of the boiler proper, for the reason that they are subjected to a high temperature throughout their entire length, while the tubes of the boiler proper are affected at only one end by the high temperature, the other end being affected by gases having only a temperature approximating that of the flue gases.

An opening is left lengthwise through the centre of the bottom of the combustion chamber, affording passage into the ash pit for ash and cinders which may form in the combustion chamber. The high

temperature immediately over the slot keeps it open and permits such liquid ash as may collect in the furnace, to drip into the ash pit below.

The temperature of the ash pit is far below the congealing point of the liquid ash, so that liquid ash as it drips from the edges of the slot becomes cooled into globular masses, which fall to the bottom of the pit and are deposited in an easily manageable condition.

This type of combustion chamber is theoretically correct in form, simple and economical of construction, and can be manufactured by the boiler maker and put in place and attached to the boiler proper without disturbing the boiler walls and with a minimum of change in the boiler setting.

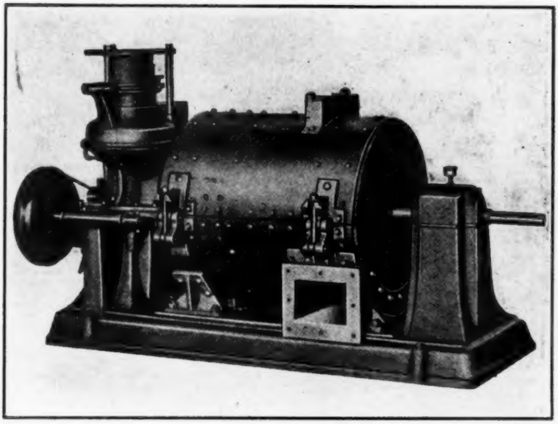

FIG. 21. AERO UNIT PULVERIZER (CLOSED).

Incidental to the satisfactory solution of the coal combustion problem is the question of the elimination of the smoke and cinders passing from the combustion chamber, through the stack and into the surrounding atmosphere. Smoke is a nuisance, polluting the atmosphere and deleterious to health and property. Its cause is incomplete combustion; its abatement and cure, complete combustion of the fuel in the furnace and complete removal of the cinders and dust from the gases of combustion prior to their emission into the atmosphere.

Smoke is generally understood to be the visible emanations from a chimney or outlet from a source of fuel combustion, such, for instance, as the furnace of a steam boiler, and is due to a lack of air at the proper temperature at the point where the volatile gases from the fuel should be burned, the result being that these gases are only partly burned and unconsumed carbon is set free, rendering the containing gases visible.

As a matter of fact, smoke is the combination of gases, fumes and dust particles resulting from the imperfect combustion of a carbonaceous fuel such as coal, lignite, coke, peat, wood or other substances. Of these three constituents, gases, fumes and dust, the gases are an unavoidable product of combustion, are invisible, make up the greatest bulk of the smoke and serve as a vehicle for carrying off the entrained fumes and dust particles.

The fumes are volatilized, unconsumed constituents of the fuel which pass off as vapors with the gases, and as the gases cool are sublimed into minute solid particles which, when emitted with the gases into the atmosphere, give a more or less dense color to them,

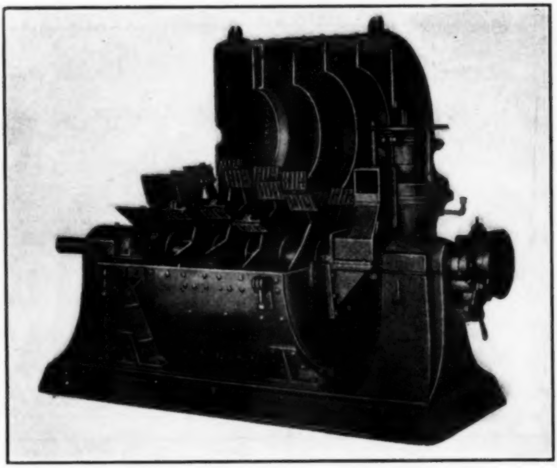

FIG. 21A. AERO UNIT PULVERIZER (OPEN).

thus rendering them visible as, for instance, the vapors of unconsumed carbon which we see and call smoke. The fumes are so fine and light and form so small a percentage of the gas volume, generally less than 1 per cent of the carbonaceous constituent of the fuel, that they float away and are gradually dissipated in the atmosphere.

The dust is composed of small particles of the incombustible portions of the fuel, which are not and cannot be consumed and which are carried off by and with the gases of combustion and, after emission into the atmosphere, are carried to varying distances from the point of emission, according to their size and weight, ultimately settling and falling on the surface of surrounding objects. This dust, generally called cinders, when coming from a boiler furnace, may be dark or light in color and also serve to give more or less color to the gases.

No matter how perfect or complete the combustion of the fuel in the furnace, thus eliminating all fumes or vapors of carbon, the cinders and dust are always present and go up the chimney just the same. It is possible to have a smokeless chimney so far as color is concerned, which is emitting large quantities of cinders and dust to the detriment of health and surrounding property. In order to remove these cinders and dust, the gases and dust content must be passed through a suitable apparatus which will remove the dust particles.

In this way, by complete combustion in the furnace and complete dust elimination at the outlet from the furnace, the gases will be freed from all fumes and dust, and will pass uncolored and invisible

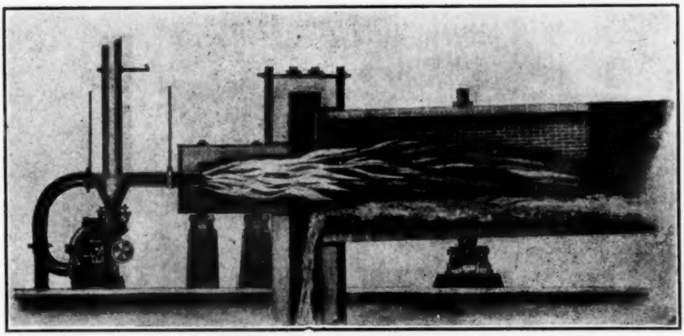

FIG. 22. UNIT PULVERIZER APPLIED TO CEMENT FURNACE.

into the atmosphere, resulting in the complete prevention and elimination of smoke.

From this it follows, that to abate and eliminate smoke, we must have the fuel in the most combustible form: we must see that it is completely consumed and we must seperate the dust content from the resultant gases.

Due to the high temperatures attained and the complete combustion of all of the fuel, pulverized coal makes a smokeless fire at all rates of burning, and the ash being very fine, a large percentage of it passes away with the gases, reducing the tendency to, and the amount of, clinkering and slagging in the combustion chamber.

For eliminating the cinders and dust carried by the gases of combustion, a dust separator, Fig. 25 and S, Fig. 24, may be placed between the boiler outlet flue 9 and the flue to the chimney.

The operation of this apparatus is as follows: the suction fan, A, rotated by the motor 25, draws the combustion gases and dust content through flue 22, into the fan where, by centrifugal force,

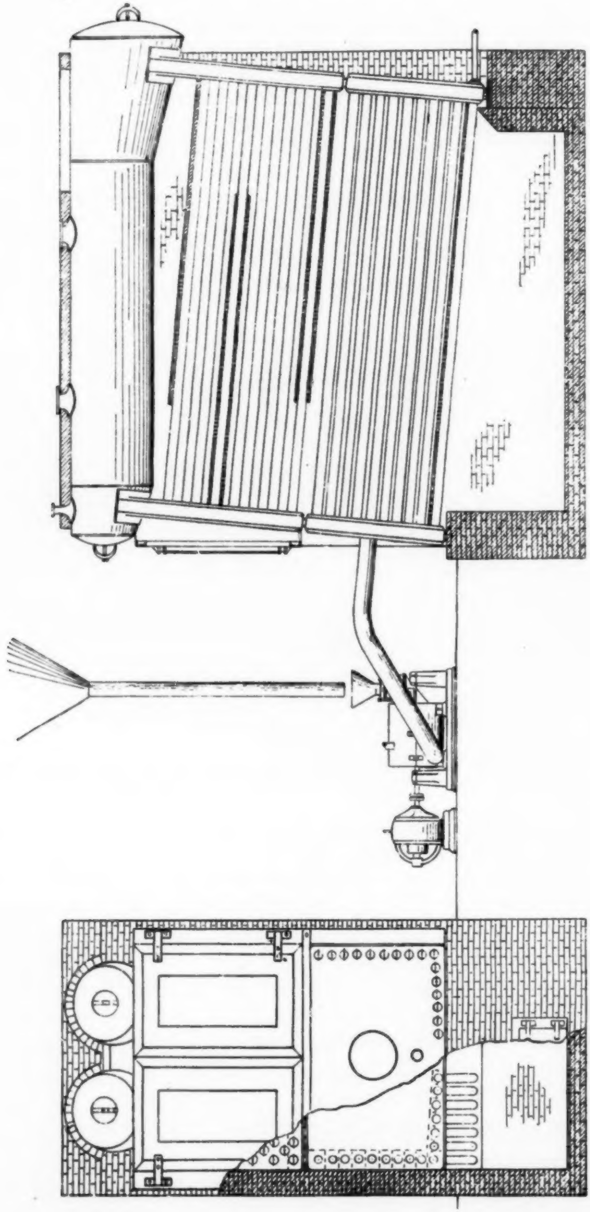

FIG. 23. UNIT PULVERIZER COMBUSTION CHAMBER APPLIED TO A WATER TUBE BOILER.

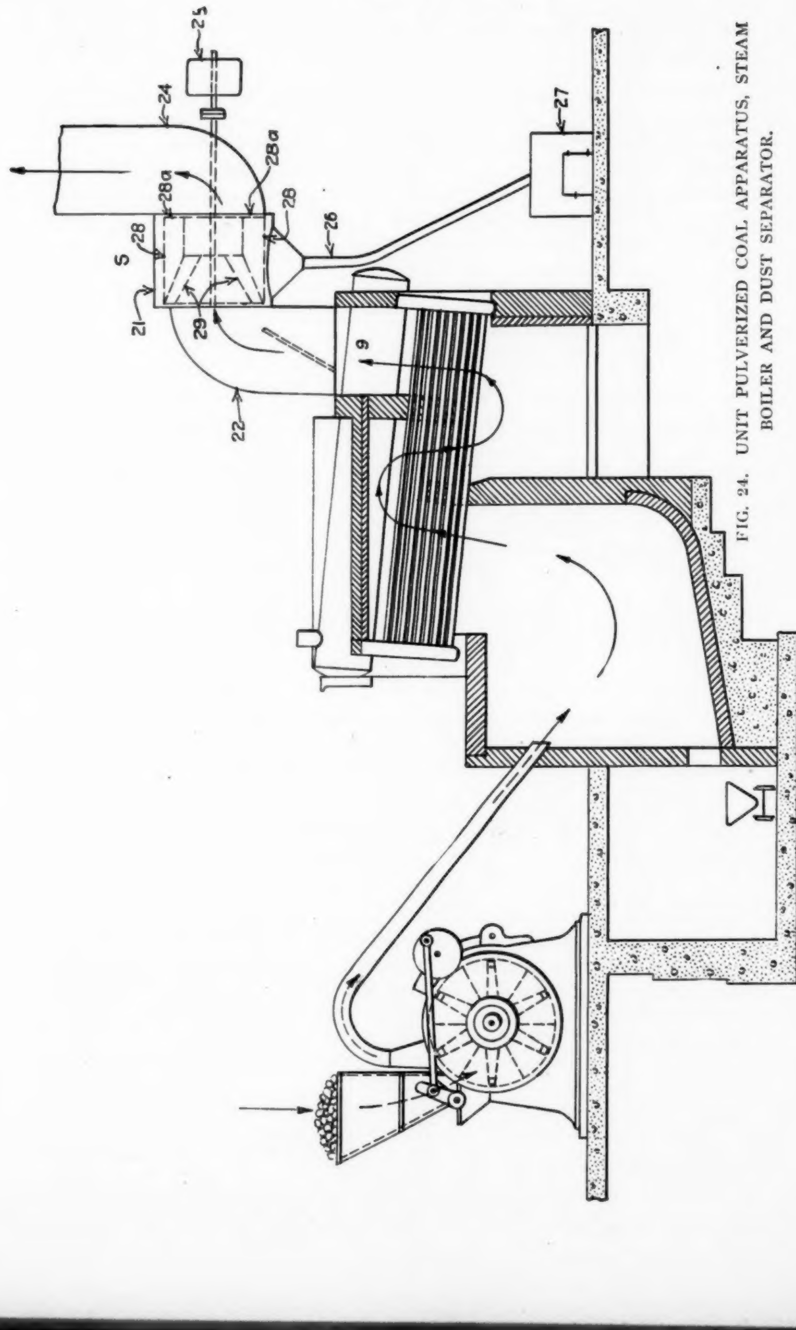

FIG. 24. UNIT PULVERIZED COAL APPARATUS, STEAM BOILER AND DUST SEPARATOR.

the gases and dust content are driven radially at a high velocity through the fan blades 29 and against the perforated circumferential portions. 28.

The cinders and dust are driven through the perforated drum and the gases, freed of their dust content pass out through openings 28a into and through outlet flue 24 to the chimney. The dust after passing through the perforated circumferential portions 28, into the chamber 21, passes to the bottom of the chamber and out through outlet and pipe 26 into the dust bin 27, where it is retained and from which it can be removed as required.

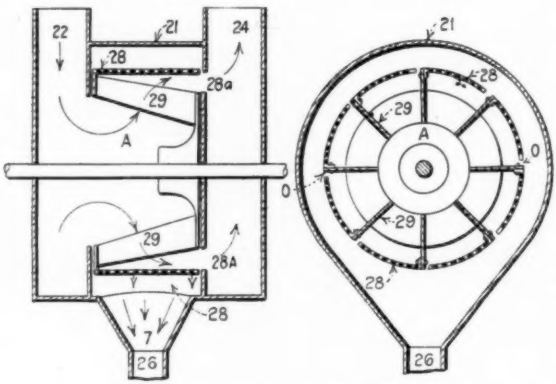

FIG. 25. DUST SEPARATOR.

The suction fan also acts as an induced draft apparatus, maintaining the necessary flue draft to draw off the gases and dust content and force the gases into, up and out of the chimney.

This apparatus will remove 95 per cent of all of the cinders and dust from the gases (cinders and dust ranging in sizes from a 10 mesh to a 350 mesh sieve) the 5 per cent remaining being so fine that it is almost impalpable and will pass through a 350 mesh sieve, and even finer.

It will be seen that by such a combination of a *unit* coal pulverizer, a properly arranged boiler combustion apparatus and a *unit* dust separator, complete combustion of the fuel is attained, the efficiency of fuel combustion, and boiler output is greatly increased, no smoke fumes are created and all cinders and dust are eliminated.

No. 558

COLOR SCHEMES FOR DISTINGUISHING PLANT PIPING

By H. L. Wilkinson[1], New York, N. Y.

Non-Member

THE importance of some definite and unmistakable means of readily distinguishing between the various pipe and conduit lines and systems in the power plant has long been recognized by both designing and operating engineers. Particularly in large power plants is this question of vital importance and it should be stated that in some of the well ordered large power plants, reasonably satisfactory systems have been installed. Also, there has been some effort made to standardize this practice, a committee appointed by *The American Society of Mechanical Engineers* to investigate the question, having reported upon the preferable distinguishing colors for the various divisions of piping systems in the usual power plant (see Transactions of The American Society of Mechanical Engineers, Vol. 33, 1911, page 17). The report of the Committee is incorporated with this paper as an appendix.

While the importance of standardization in this detail of our power plants has been recognized, too little attention has been given to the matter of late and the writer believes that its importance should not be overlooked. It is therefore suggested that the Members of the Society consider the adaptation shown in Table 1 of the report presented to *The American Society of Mechanical Engineers* in 1911 and designed to apply to all piping systems.

It will be noted that the recommendation involves, in addition to piping lines, color schemes for machinery, motors, hand rails, dadoes, waste pails, elevator cages, etc., thus extending the usefulness of this distinguishing system to all parts of the industrial plant. It has been a revelation to the writer to find the cordial reception which this proposed color scheme has received in many industries and concerns of national prominence, and the result is that new industries and concerns are taking it up continually. The application of this standardization might well be extended to the designation by distinguishing colors of tools used in various departments of a plant. This would bring about several benefits. In the first place, it would

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enable managers to hold each department of a plant responsible for its own tools. Then, because of the improved appearance of the tools it would create more interest in their care on the part of mechanics. Last, and not least, it would surely prove an insurance against tools being carried out of factories.

While this scheme designates definite colors for certain pipes, it is of course unnecessary to apply any one particular color on any one pipe, the arrangement being flexible so that an engineer may determine for himself his own design. In some cases, where there are as many as 15 to 25 various pipe lines, it is necessary to use combination colors on some pipes, painting the straight pipe one color and the joints, valves, elbows, etc., the alternating color.

TABLE 1. COLOR DESIGNATIONS FOR DIFFERENT CLASSES OF PIPING

Class of Piping	Color
Sprinkler Pipes, Fire Pails, etc.	Vermilion
Compressed-Air Pipes	Dark Gray
Oil Pipes	Brown
Electric Light and Power Conduits	Black
Steam Power Lines	Blue
Steam Exhaust Lines	Buff
Hot-Water Pipes	Bright Red Oxide
Cold Water Pipes	Yellow
Motors and Machinery	Bright Green
Refrigerating Lines	Maroon
Elevator Cages, Fire Doors, Waste Cans, Railings, Shelves, etc.	Bronze Green or Black
Steam Heating Lines and Radiators	Aluminum Gray

Reproduced from a chart in colors which appears in the booklet entitled, Character Paints for Mill and Factory, published by the Debevoise Co. Copies of the booklet may be obtained upon application to the Company.

Of course, some exceptions to personal selection will be found where an established custom has been in effect for some time, as in the case of sprinkler pipes and all fire lines, where vermilion is the logical color to use.

The advantage of this standardization will become readily apparent from the case of a certain plant where there was a stoppage or break in one of the pipe lines. The workmen carefully followed the line to the side wall where the trouble apparently existed and opened up the wall for a considerable area, only to be confronted with everything but the line they sought. Of course, the expense of ripping out the wall was nothing compared to the inconvenience and loss sustained, due to the suspension of operation until this repair was made. If this pipe line had been painted with a distinguishing color and a small arrow placed on the wall where the pipe entered, indicating the direction the pipe took after entering the wall, all this time and difficulty would have been obviated.

Another condition which very often arises is the leaking of a pipe on the third, fourth, or some upper floor of a building. The engineers, usually on duty on the first floor or in the basement, would

naturally be informed of the leak by the person discovering it but, without a doubt, in the majority of cases the person reporting would be unable to tell the engineer which line of pipe was at fault, thus necessitating a journey from the basement to the floor in question. Furthermore, while it might be possible to shut off the pipe at a point convenient to the leak, probably it would be necessary for him to go back to the engine room and shut off the main valve. If, on the other hand, the individual discovering the leak could immediately telephone to the engineer that the blue, green, yellow, brown or black pipe was leaking, it would thus be possible at the main valve to instantly stop further leakage.

Another instance recently brought to the writer's attention is pertinent in showing vividly the value of standardization. One Sunday the watchman in a dye plant discovered that a pipe carrying a valuable liquid was leaking. The engineer was out of the city, which necessitated the watchman calling the manager. The manager was unfamiliar with the beginnings and endings of the maze of pipes and it was only after considerable time that he was able to locate the proper valve to shut off. In the meantime considerable damage had been done, to say nothing of the loss of a large quantity of valuable acid. How easily the watchman could have stopped the leaking and prevented the damage if he had been guided immediately to the correct valve by following the color of the leaking pipe to the first valve of the same color.

Such a distinguishing system would appear to the writer to be indispensable in a plant with pipe lines carrying oil for automatic lubrication and acids for the treatment of goods in manufacture. A break in an acid pipe line, if not immediately isolated may cause damage not only to large quantities of material but harm to the workers as well.

These simple illustrations have shown only one phase of the advantages of standardization. It will be readily recognized that the adoption of the standardization method in many plants will often carry with it the painting of pipes that heretofore have gone unprotected. Special paints are obtainable for these purposes, that possess the qualities of remaining uncracked under extremes of temperature, withstanding corrosion, and affording superior protection against rust. An enamel paint is most suitable for general piping but for power house and other canvas-covered pipes a high-grade linseed-oil paint in white and colors should be used. The greatest benefits from the adoption of a method of standardization will accrue where careful thought is used in the selection of paints especially designed for this purpose. In cases where the surfaces to be painted are subject to unusually severe conditions of exposure to corrosion, a rust preventive paint of established merit should be used for the first coat followed with the standardization paint in the colors selected.

Of direct importance to the members of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS are the results of exhaustive tests made some time ago at the University of Michigan, showing the increased heat refraction from radiators painted with enamel as compared with those painted with aluminum or gold bronze. While the increased heat refraction from a single radiator may not

appear to be of consequence, it nevertheless does result in a considerable fuel saving when the aggregate of all the radiators in a building is figured. A transcript of these tests is appended It is interesting to note that the coating with which the radiator is finally finished is unaffected by the coat or number of coats previously applied. It is of further interest to note that lighter colored enamels possess greater heat refraction than darker colors Where light colored enamels are applied there is a tendency to darken in various degrees according to the amount of heat in the pipes. However, the change is comparatively slight and uniform and in the color only, the coating remaining intact. Because of the glossy finish of the enamel it is more readily cleaned than bronze. Best results are obtained when the radiators and pipes are painted while cold.

APPENDIX I

REPORT OF COMMITTEE ON IDENTIFICATION OF POWER HOUSE PIPING

Reprinted from Transactions of The American Society of Mechanical Engineers, Vol. 33, 1911, *page* 17

a. In the main engine rooms of plants which are well lighted, and where the functions of the exposed pipes are obvious, all pipes shall be painted to conform to the color scheme of the room; and if it is desirable to distinguish pipe systems, colors shall be used only on flanges, fittings and on valve flanges.

b. In all other parts of the plant, such as boiler house, basements, etc., all pipes (exclusive of valves, flanges and fittings), except the fire system, shall be painted black, or some other single, plain, durable, inexpensive color.

c. All fire lines (suction and discharge), including pipe lines, valve flanges and fittings, shall be painted red throughout.

d. The edges of all flanges, fittings or valve flanges on pipe lines larger than 4 in. inside diameter, and the entire fittings, valves and flanges on lines 4 in. inside diameter and smaller, shall be painted the following distinguishing colors, numbered 1 to 12, inclusive:

DISTINGUISHING COLORS TO BE USED ON VALVES, FLANGES AND FITTINGS ONLY

Steam division	*a.*	High pressure—white
	b.	Exhaust system—buff
Water division	*c.*	Fresh water, low pressure—blue
	d.	Fresh water, high pressure boiler feed lines—blue and white
	e.	Salt water piping—green
Oil division	*f.*	Delivery and discharge—brass or bronze yellow
Pneumatic division	*g.*	All pipes—gray
Gas division	*h.*	City lighting service—aluminum
	i.	Gas engine service—black, red flanges
Fuel oil division	*j.*	All piping—black
Refrigerating system	*k.*	White and green stripes alternately on flanges and fittings, body of pipe being black
Electric lines and feeders	*l.*	Black and red stripes alternately flanges and fittings, body of pipe being black

COMMITTEE ON IDENTIFICATION OF POWER HOUSE PIPING.

APPENDIX II

PAINT FOR STEAM AND HOT WATER RADIATORS

In a series of investigations carried out in 1909 at the University of Michigan, by John R. Allen, Professor of Mechanical Engineering, it was clearly demonstrated that the nature and color of the paint applied to radiating surfaces exert a material influence on their heating efficiency. It has also been conclusively demonstrated that this influence is confined exclusively to the final coat applied, irrespective of the number or nature of the underlying coats.

These experiments and results were given in detail by Professor Allen in a paper presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, at Indianapolis, in 1909, and later before the NATIONAL DISTRICT HEATING ASSOCIATION convention, at Pittsburgh, in June, 1911.

From the paper last mentioned, the following is quoted:

"The painting of radiators may materially affect the transmission of heat A series of experiments was conducted about two years ago to determine the effect of painting. Two cast-iron rectangles were used; one was painted and the other left unpainted so that the painted radiator was always compared with the same unpainted radiator. The results of these tests were very interesting. The radiators were first tested both unpainted and the condensation in the two was practically alike. One radiator was then painted with two coats of copper bronze and it was found that the heat transmission was reduced 24 per cent from the original cast-iron. Two coats of copper bronze were then placed upon a radiator and the heat transmission was reduced 25 per cent. Two coats of terra cotta enamel were then placed over the four previous coats and the heat transmission was 3 per cent better than the original cast-iron unpainted. This was repeated for fourteen coats, the last two coats being aluminum bronze. The transmission then showed a reduction of 27 per cent and additional tests were conducted with various enamels, japan, lead paint, and zinc paint. The results of these tests are shown in the following table:

TABLE 1. EFFECT OF PAINTING RADIATORS

No. of Test	Average room tem.	Average tem. of steam entering rad.	Condensation per hr. per sq. ft. actual surface	B.t.u.'s rad. per hr. per sq. ft. of surface per deg diff. of tem.	Efficiency
1	74.4	222	0.413	2.82	0.997
2	76.0	220	0.418	2.94	1.005
3	63.1	224	0.353	2.16	0.761
4	72.3	220	0.325	2.08	0.752
5	74.5	220	0.436	2.86	1.038
6	66.3	218	0.351	2.24	0.735
7	74.1	224	0.421	2.67	0.977
8	72.9	226	0.431	2.67	0.977
9	71.8	225	0.318	1.97	0.730
10	70.5	224	0.324	2.005	4.724
11	66.7	223	0.442	2.68	0.970
12	67.6	224	0.452	2.75	1.01
13	64.2	224	0.446	2.66	0.997
14	64.0	224	0.429	2.545	0.956
15	70.6	224	0.423	2.62	0.997
16	68.5	224	0.364	2.22	0.850
17	67.0	224	0.347	2.02	0.760
18	86.9	224	0.379	2.62	0.987
19	83.4	224	0.389	2.65	1.00
20	86.8	224	0.374	2.59	0.989
21	77.2	224	0.423	2.72	1.00
22	77.7	224	0.408	2.66	0.964
23	76.0	224	0.418	2.70	1.01

REMARKS:

Radiator No. 2 Plain in all tests

These paints of two coats each were painted over one another in the order given.	1. Rad. No. 1 Plain as received from factory
	2. Rad. No. 1 Plain as received from factory
	3. Rad. No. 1 Painted with Copper Bronze
	4. Rad. No. 1 Painted with Copper Bronze
	5. Rad. No. 1 Painted with Terra Cotta Enamel
	6. Rad. No. 1 Painted with Copper Bronze
	7. Rad. No. 1 Painted with Light Brown Varnish
	8. Rad. No. 1 Painted with Oak Brown Varnish
	9. Rad. No. 1 Painted with Aluminum Bronze
This series follows one another.	10. Rad. No. 1 Painted with Aluminum Bronze
	11. Rad. No. 1 Painted with Silver Gray Enamel
	12. Rad. No. 1 Painted with Snow-White Enamel
	13. Rad. No. 1 Painted with Bronze Green Enamel
	14. Rad. No. 1 Painted with No Lustre Green Enamel
	15. Rad. No. 1 Painted with Maroon Gloss Japan
	16. Rad. No. 1 Painted with Shellac and Copper Bronze Powder
	17. Rad. No. 1 Painted with Copper Bronze Powder and Linseed Oil
Painted over one another.	18. Rad. No. 1 Painted with White Paint
	19. Rad. No. 1 Painted with Terra Cotta Paint
	20. Rad. No. 1 Painted with Light Green Paint
	21. Rad. No. 1 Painted with Light Green Paint, Zinc
	22. Rad. No. 1 Painted with Terra Cotta Paint, Zinc
	23. Rad. No. 1 Painted with White Paint, Zinc

"In general the table shows that aluminum, copper and metal pigments in the bronzes reduce the heat transmission. This is probably largely due to the composition of the bronze and partly to the vehicle which contains this pigment. Enamel, lead paints, and zinc paints almost all show no loss in heat transmission. The experiments show that the effect is largely surface effect and not conduction effect. The results show that the loss of heat from radiators depends largely upon the surface effect and to a very small extent upon the conduction of heat through the metal."

It will be seen that in these tests the best results were obtained by the use of a snow white enamel (No. 12) and a zinc oxide paint (No. 23), the two showing exactly equal efficiency.

No. 559

THE SEMI-ANNUAL MEETING

1920

AMERICAN SOCIETY OF HEATING & VENTILATING ENGINEERS

THE Semi-Annual Meeting of 1920 of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS offered a second opportunity for a visit of the membership to the city of St. Louis, Mo., the furthest western point at which a meeting of the Society has ever been held. The Meeting was held jointly with the spring meetings of *The American Society of Mechanical Engineers* and *The American Society of Refrigerating Engineers* and the result was an unusually large attendance and a wide variety of greatly diversified subjects presented for discussion. Owing to the early date of the Meeting (May 26, 27 and 28) exceptionally fine weather was experienced, and the various sessions were characterized by the large attendance and the close interest given to their discussions.

In the selection of St. Louis as the headquarters for this Semi-Annual Meeting, the Society became the guest of one of its newest local Chapters and an unusually enthusiastic Meeting was the result. Bountiful entertainment was provided by local committees and the array of technical subjects of professional interest was unequalled. St. Louis proved also to be inherently rich in its attractions for engineers interested in this branch of the profession, as in many lines of industry, it was found to excel—particularly with regard to details of school buildings and equipment.

Since the last Meeting held by the Society at St. Louis (1910), the city has experienced a tremendous growth. At the time of this Meeting, the population had just been reported by the recent census as 773,000, and it is now claimed that within a radius of 500 miles from this center, there is a total of over 40,000,000 people. The city is now considered one of the greatest railroad centers in the United

States, if not in the whole world. It is also served by numerous freight packet lines of distribution on the Mississippi and Missouri rivers. One of the most important features of attraction in St. Louis, proved to be the public school system which has been developed to an unusually high standard from the standpoint of buildings and equipment, and those of the members who were interested in school building ventilation were afforded an unusual treat. Professional papers were presented at the sessions which discussed important innovations in school ventilation and as a result the meeting proved of unusual interest on ventilation topics. One of the striking results of the Meeting was the establishment of the well-known Synthetic Air Chart originated by Dr. E. Vernon Hill, as the standard of official measure of ventilation of the Society; this was undoubtedly the most important action taken at this Meeting and will for a long time to come characterize it as the great feature of importance evolved there.

The headquarters of the Meeting was located in the building of the Board of Education of the city of St. Louis, through the courtesy of which the Board of Education assembly room was placed at the disposal of the Meeting. As this location was but one block from the hotel headquarters (Hotel Statler), the arrangement proved most convenient to the visiting members. The registration headquarters was placed in the main corridor of the Board of Education offices, which adjoined the assembly room and proved a most convenient arrangement. The registration totalled 130, of which 63 were members. All the sessions were held in this assembly room with the exception of the joint session with *The American Society of Mechanical Engineers* and *The American Society of Refrigerating Engineers* which was held in the meeting room of the former Society at the Hotel Statler headquarters. In addition, *The American Society of Refrigerating Engineers* met in joint session with the Society on Wednesday afternoon, which was conducted at the Board of Education assembly room.

PROGRAM OF THE SEMI-ANNUAL MEETING
1920

FIRST SESSION

Wednesday, May 26, 10 A. M.

BUSINESS SESSION:
- Welcome Address.
- Response by President.
- Annual Reports of Chapters.
  - Illinois.
  - Kansas City.
  - Massachusetts.
  - Michigan.
  - Minnesota.
  - New York.
  - Western New York.
  - Ohio.
  - Eastern Pennsylvania.
  - Pittsburgh
  - St. Louis.
- Reports of Committees.
  - Committee on Industrial Unrest and the Problem of its Solution.
  - Committee to Investigate Capacities of Steam and Return Mains.
- Report of Director of Research on Synthetic Air Chart as a Standard for Ventilation.

SECOND SESSION

Wednesday, May 26, 2 P. M.

JOINT PROFESSIONAL SESSION WITH THE AMERICAN SOCIETY OF REFRIGERATING ENGINEERS:
- Paper:
  - New Methods for Applying Refrigeration, by E. S. H. Baars.
  - (Furnished by the Am. Soc. of Refrigerating Engineers.)
- Paper:
  - Theory of Heat Losses from Pipes Buried in the Ground, by J. R. Allen.
- Paper:
  - Heat Insulation Facts, by L. B. McMillan.
- Paper:
  - Automatic Control of Temperature, by R. P. Brown.

THIRD SESSION

Thursday, May 27, 10 A. M.

JOINT PROFESSIONAL SESSION WITH THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS AND THE AMERICAN SOCIETY OF REFRIGERATING ENGINEERS (AT HOTEL STATLER):
- Paper:
  - Weir for Gaging the Flow of Water in Open Channels, by Clemens Herschel.
  - (Furnished by the Am. Soc. of Mechanical Engineers.)
- Paper:
  - Simplification of Venturi Meter Calculations, by Glenn B. Warren.
  - (Furnished by the Am. Soc. of Mechanical Engineers.)
- Paper:
  - Dissipation of Heat by Various Surfaces, by T. S. Taylor.
  - (Furnished by the Am. Soc. of Mechanical Engineers.)
- Paper:
  - The Thermal Conductivity of Heat Insulators and a Proposed Standard of Testing Commercial Insulating Materials, by M. S. Van Dusen.
  - (Furnished by the Am. Soc. of Refrigerating Engineers.)
- Paper:
  - Ship Ventilation, by F. R. Still.

FOURTH SESSION

Friday, May 28, 2 P. M.

SCHOOL VENTILATION SESSION:

Paper:
The Significance of Odorless Ozone, by E. S. Hallett.

Paper:
High Efficiency Air Flow, by F. W. Caldwell and E. N. Fales.

Paper:
The Sizing of Ducts and Flues, by H. Eisert.

Paper:
Observations of an Auditorium Having Air Inlets in the Window Sills, by S. R. Lewis.

Paper:
The Ventilation of Large Auditoriums, by R. S. M. Wilde.

Paper:
The Training of Janitors and Custodians, by E. S. Hallett.

FIFTH SESSION

Friday, May 28, 2 P. M.

PROFESSIONAL SESSION:

Report on Standard Code for Testing Heating Systems.

Symposium on Health and Humidity.

Paper:
The Relation of the Death Rate to the Wet Bulb Temperature, by E. V. Hill and J. J. Aeberly.

Paper:
The Relation of the Wet Bulb Temperature to Health, by O. W. Armspach.

Paper:
Commercial Dehydration, by J. E. Whitley.

Paper:
Industrial Electric Heating, by Wirt S. Scott.

No. 560

REPORT OF COMMITTEE ON INDUSTRIAL ENGINEERING

The conviction which had grown in the minds of men that the problem of economic reconstruction is very largely an engineering problem, found expression in this Society in the appointment, by New York Chapter, of a Committee on Industrial Engineering, to present a brief statement of economic and industrial unrest problems and submit recommendations for Society action. The subject was considered one of fundamental importance.

THE following report of a Committee of New York Chapter covers a brief presentation of: *Causes of Industrial Unrest; Remedies Needed; Responsibility of Engineering Profession; Declaration of Principles.* The report also includes recommendations for our Society's action.

INDUSTRIAL UNREST

Present industrial unrest is due to a combination of causes among which are:

a. Our failure to have *human relations* keep pace with industrial development, and to direct industrial development within the limits of reasonable endurance.

b. Failure of both Capital and Labor to accord due consideration to each other and to properly co-operate, with the object of making service to society and public welfare a matter of first consideration.

c. Our failure to measure up to our opportunities and responsibilities under the conditions, at home and abroad, growing out of the war with Germany.

d. Our failure to properly regulate administration of business credit and to prevent undue currency inflation.

e. High cost of living brought about by war conditions.

Presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, St. Louis, Mo., May, 1920.

REMEDIES NEEDED

The industrial unrest situation requires not only a great educational campaign and scientific study and practical application, but also much immediate constructive action. Some of the items requiring immediate consideration are:

a. Establish a sound *declaration of principles* for guidance in industry.

b. Put *human relations* in the lead in industry.

c. Supply arbitration and conciliation machinery, through Federal enactment, to promote settlement of dispute between employer and employee with the public represented, as recommended by the Second Industrial Conference.

d. See that public offices are filled by men who are competent and who desire to serve for the public good.

e. Secure proper leadership both in politics and industry and an aroused public opinion back of such leadership.

f. Place administration of credit on a sound basis of public service and safeguard it by some legal limitations.

g. Find ways to interest men in their jobs.

h. Provide scientific reduction of what may be termed "physical and mental fatigue in industry."

i. Establish some responsible agency of continuous productive initiative, which will include such questions as survey of supply and demand and the balancing of material and labor expenditure between necessities and luxuries.

j. Create some means of adequate co-ordination between the different organized constructive agencies now at work to promote better collective results.

k. Improve housing and recreational facilities at industrial centers of activity.

l. Regulate employment methods and maintain a government employment bureau.

m. Arrange for a systematic follow-up and protection of immigrants for a reasonable time upon entrance to our Country.

n. Study labor agitations such as the Plumb plan, consumers cooperation, etc.

o. Secure enactment of legislation to curtail the abuses of both capital and labor.

p. Legislate heavy penalties upon exploitation, bribery and profiteering.

q. Regulate the news service of the Country to more adequately render public service and to embody American ideals.

r. Urge and assist the churches of the Country to unite in a broad program to extend the application of the Christian principles of life to an every day practice in business and industry.

s. Encourage the placing of only thoroughly trained men of experience at the head of industries and at the head of boards of directors controlling industries.

t. Apply the principle of industrial competence to both management and labor. This can be done only through continuous education, training and experience.

RESPONSIBILITY OF ENGINEERING PROFESSION

Men of vision and authority in industry have recognized that among all classes of men represented in industry the *Industrial Engineer* stands out as best fitted by training and experience to take the leadership in its re-adjustment problems. It is important for the engineering profession generally to realize this fact and to help shoulder the responsibility that goes with it by promoting concerted action on the part of engineering societies to grasp the opportunity and discharge their duty to Society.

The American Society of Mechanical Engineers at its annual meeting in December, 1919, adopted the following:

"DECLARATION OF PRINCIPLES"

Social and industrial unrest result from the fact that human relations have not kept step with economic evolution.

Competent directive management of essential enterprises is the logical solution. Such management must be free from autocratic control, whether by capital or by labor.

Sharp social or industrial disputes are no longer private. Society is affected, therefore such cases must be subject to the decision of authorities based upon intrinsic not arbitrary law.

Industry and public utilities must serve the people. There is no room for special privilege of capital or of labor. Strikes, irregular employment, or arbitrary acts of ownership or of management are harmful, not alone to the immediate parties but to society as a whole.

Productivity and public service are absolutely essential.

On account of the peculiarly intimate familiarity of engineers with industrial problems our responsibility is great.

Therefore, we, engineers and members of *The American Society of Mechanical Engineers,* declare that the following essentials are established by facts and experience, urge all of our members to uphold them, and invite other engineers to cooperate with us in having them unanimously recognized, viz:

> Every important enterprise must adopt competent productive management, unbiased by special privilege of capital or of labor. and disputes must be submitted to authorities based upon intrinsic law.
>
> Credit capital represents the productive ability of the community and should be administered with the sole view to the economy of productive power, that is, it should be granted only to those who are able to render valuable service.

RECOMMENDATIONS

1. That our Society approve the action taken by *The American Society of Mechanical Engineers* in establishing a "Declaration of Principles" as being essential to proper industrial re-adjustment, and that our Society adopt the same "Declaration of Principles."

2. That the Society appoint a standing Committee of Five Members (with privilege of appointing sub-committees). That the duties of such Committee consist particularly of the following:

a. To study the subject of economic and industrial problems and carry on a campaign to inform and to arouse interest of our Society Membership in the responsibility and opportunity of the Engineer to assist, individually and collectively, in the present situation.

b. To co-operate with committees of other engineering societies:

x. In developing interest and a sense of responsibility of engineers, and the engineering profession generally, with a view to united constructive action.

y. In developing and carrying out a comprehensive educational campaign for a term of years.

z. In supporting and helping to co-ordinate and make effective all good constructive agencies such as, the Second Industrial Conference at Washington as represented by its report recently made public, the Interchurch Movement, etc.

Respectfully submitted,

FRANK T. CHAPMAN, *Chairman.*
FRANK K. CHEW,
WM. H. DRISCOLL,
J. IRVINE LYLE,
CHAMPLAIN L. RILEY.

DISCUSSION

F. T. CHAPMAN: New York Chapter at an early meeting on the subject of industrial reconstruction adopted this declaration of principles which *The American Society of Mechanical Engineers* had adopted at their convention last December. We are now suggesting that our Society take the same action.

It seems to me that the first question to be taken up should be whether the Society wishes to go on record as adopting recommendation (*a*).

J. H. DAVIS: I move the adoption of recommendation (1).

The motion was seconded by Theo. Weinshank.

JOHN HOWATT: Mr. Chapman, what is meant by the use of the words "authorities based upon intrinsic law."

F. T. CHAPMAN: In case of a serious dispute, there must be a court of last resort to make the final ruling, and the idea is that this shall be an authority which in our judgment would be the Federal Government, acting through just such a set of machinery as the Second Industrial Conference has provided for. The word "intrinsic" means nothing more than true, essential and real.

W. B. CLARKSON: How much thought have the A. S. M. E. and our Committee given to this in the promulgation of the Declaration of Principles as it relates to the farming community? It is well known that farming activities are a very important element in our industry as a whole. I am wondering how much thought the Committee did give to the question of the farmer and the difficulties that he is encountering at this time. Of course, I can see in an indirect way, that some of these recommendations apply to his as well as they do to all other industries; but agriculture needs a special treatment, that should be distinct as a class.

F. T. CHAPMAN: The New York Section of *The American Society of Mechanical Engineers,* which represents nearly 3000 members to-day, had a series of meetings last fall on the general question of industrial unrest, and as a result of those meetings, a committee of five was appointed by the New York Section to draw up a Declaration of Principles. They were to be general principles upon which could be based a general readjustment plan, and they are supposed to apply to farmers as well as to the industries. I think the farmers necessarily come under the general term industry in a very large sense, although they are usually classed under agriculture.

The Declaration of Principles was drawn up by the Committee and presented to a very full meeting, about four hundred present in November, and after considerable discussion they were unanimously

adopted by the New York Section. Finally in December, at the A. S. M. E. Annual Meeting, after quite a stormy session, they were passed, unanimously; at least there were not more than two or three dissenting voices.

The general items enumerated in the report are simply suggested items that the New York Chapter Committee has included in presenting the subject to the Society, in order to indicate some points which it thought required consideration. However, these general items are not, in any way, included in the recommendation to adopt the Declaration of Principles as already adopted by *The American Society of Mechanical Engineers.*

THE PRESIDENT: Of course, it is manifestly impossible for us to go into all the various economic phases of industrial unrest, and so at this moment it would appear to me that if there is nothing objectionable in this Declaration of Principles, and it would be strange indeed, if *The American Society of Mechanical Engineers* had adopted something which was objectionable; it certainly can do no harm and it might do a great deal of good for us also to adopt this recommendation.

A motion was seconded and carried for accepting the recommendation.

The second recommendation of the Committee was read as recommendation (2).

FRED. R. STILL: I do not believe that anything will be accomplished by a sub-committee of such character. The times are very much upset, and within the past 30 days conditions have changed, so that I do not believe there is any real work for the Committee to do. If the Federal Reserve Board sticks fast to its present policy, I think a large part of this so-called industrial unrest will tend to subside.

The conditions that prevailed in our various plants have been such that one did not dare tell a man what he ought to do, or that he was doing a poor piece of work, for he would quit immediately. That situation has prevailed all through our plant, and we have a bonus system, profit sharing, life, accident, and health insurances, and everything else in the way of benefits that have been going around. We have tried every scheme that has ever been presented to anybody to get them to take a live interest, but all to no avail. Conditions have begun to change in the past 30 days, so that now if a man does anything wrong one can tell him where to "get off" and he does more as he is told, because at the present time in the City of Detroit, it is estimated that there are about 30,000 men out of work, and those who have one are sticking to their job.

One of the elements in connection with this problem of social unrest in the large industrial centers, is the drudgery of the job. All of us have concentrated too much—one man having too much of one thing to do. A man left the Ford factory and applied for a

job as a mechanic in another shop. He was asked what he had been doing, and replied he was putting in bolt No. 32. That illustrates the point I am getting at.

I think that inside of a year from now, after things settle down to normal conditions, there will be no necessity for the proposed Committee. I am not opposed to this "Declaration of Principles." I think it is all right; but I do not think it is going to get us anywhere. I am optimistic enough to believe that there isn't anything wrong with this country; that there isn't anything seriously wrong with our industrial conditions any more than there was before the war. Just sit tight, use good judgment, be just and fair, and this thing will wash itself out.

One of the greatest problems of the day is the housing conditions all over the country. People are leaving the country and going into the cities.

F. T. CHAPMAN: This list that the Committee of the New York Section presented under heading, "Remedies Needed," has in itself enough food for thought to show that there is immense need and big opportunity for work to be done. I do not mean to say that we will not get along in this country without appointing such a committee: but other societies are getting wide awake to the work to be done, and there are many things that need to be studied, and our Society should be active on this subject. *The American Society of Mechanical Engineers* are on the verge, I believe, of undertaking various activities for industrial betterment including an extensive educational campaign. It seems to me that we would be short of our opportunity and duty if we did not pass resolution No. 2 calling for the appointment of a committee to study the situation and co-operate with other engineering societies.

JOHN HOWATT: There are a great many good points raised on this list of remedies. We have taken care of the Declaration of Principles and there are good points raised there that should be considered whether times are good or bad. A man that works for a living is entitled to conditions that these recommendations will give him. I think the Committee should be appointed, regardless of the fact whether there is a surplus of labor or not.

F. R. STILL: Most of the work that has been done by investigators of industrial conditions and the recommendations, as far as I have been able to observe, have been largely by people who have nothing to do with industry. I think that the Committee should consist of men who know the conditions which prevail in industrial plants.

W. B. CLARKSON: Another important condition of the day is that men and women engaged in primary production in the field, forest and mine, are entirely too few, and this is the key to the whole situation. In a very large way I believe that if this condition is cured it will relieve all the other conditions.

What we need to do as a Society is to study how we may help agriculture, forestry and mining, to get the men and women out to the land engaged in primary production, and to help them make their permanent homes there.

In New York City, for example, I assume that there are perhaps one-fifth of the population, and perhaps the proportion is even greater than that, of men and women who are engaged in pursuits that do not fit them. A large proportion of these belong out on the farm, and not in the city at all. If these people were transported out to their rightful places that would at once relieve the congestion in the housing of the people of New York. It may be argued that that would take men away from production in New York, but my answer is that it would not take one single man or woman away from production in New York that really belonged there. It would simply transport those who did not belong there out to their proper place.

THE PRESIDENT: All who are in favor of the motion, please manifest it by the usual sign. Contrary—the motion is carried.

No. 561

QUESTIONNAIRE ON STANDARD SIZES OF STEAM AND RETURN MAINS

At the 1919 Annual Meeting of the Society, the appointment of a Committee was authorized to collect data on standard sizes of low pressure steam and return mains. The accompanying tables of pipe sizes and list of questions were submitted for the purpose of collecting this information.

The various Chapters were requested to appoint subcommittees to aid in the work. The tables and questions above referred to were published in the Journal so that they might be available for discussion at Chapter Meetings, and so that the members and others interested might give the Committee a complete report of their present practice.

The number of distinct types of systems has increased so much since this subject was previously investigated in 1906 *that it has been thought necessary to prepare a separate table for each type of system.*

The questions submitted are as follows:

1. Have you made any test or observation to determine the critical velocities at which the down-flow of condensation in steam risers is balanced by the up-flow of steam?

2. Have you collected any field data on the increase in friction in steam mains, due to entrained water and condensation and to the average number of fittings in standard installations, over that of straight pipe and dry steam?

3. Have you any information that might be used in the compilation of a table of vacuum-system return mains for any desired drop in vacuum similar to that of Table No. 5, on steam mains?

4. You are requested to check the portions of the various tables which agree with your present practice, and to submit complete tables of the sizes which you use where your practice differs from these tables.

JAMES A. DONNELLY, *Chairman.*

TABLE 1. STANDARD ONE-PIPE STEAM SIZES—CAPACITIES IN RADIATION, SQ. FT.

Size in.	Steam Main and Down-feed Risers	Up-feed Risers	Radiator Connections	Wet Drip Main	Dry Drip Main
1	40	40	24	1,600	75
1¼	75	75	60	3,000	150
1½	150	125	100	6,000	300
2	300	280	200	12,000	500
2½	500	460		20,000	1,500
3	900	670		36,000	2,800
3½	1,500	900		60,000	6,000
4	2,000	1,200		80,000	13,000
4½	2,800	1,500			18,000
5	3,600	1,860			23,000
6	6,000	2,700			37,000
7	9,000				55,000
8	13,000				78,000
9	18,000				
10	23,000				
12	37,000				
14	55,000				
16	78,000				

Steam Riser in.	Drips to Wet ret. in.	Drips to Dry ret. in.
1	¾	¾
1¼	¾	¾
1½	¾	1
2	1	1
2½	1	1¼
3	1	1¼
3½	1¼	1½
4	1¼	1½
4½	1¼	2
5	1½	2
6	1½	2½

The steam, as well as the wet and dry drip mains and down flow risers, are calculated for a drop in pressure of 1 oz. to 100 ft. in straight pipe.

The up feed risers and radiator connections are presumed to be rated at such a capacity as will allow of the flow of the condensation in opposition to the steam flow, without causing objectionable accumulations of water in the risers or radiators or at a velocity of about 30 ft. per second in the risers and 15 ft. in the radiator connections.

TABLE 2. STANDARD STEAM AND RETURN PIPE SIZES FOR ORDINARY TWO-PIPE GRAVITY SYSTEMS—CAPACITIES IN RADIATION, SQ. FT.

			DRY RETURNS			
				Risers to		
Pipe Size, in.	Steam Main	Wet Return	Main Return	Wet ret.	Dry ret.	Rad. Conn.
¾	20	800		150	40	40
1	40	1,600	75	300	75	75
1¼	75	3,000	150	500	150	150
1½	150	6,000	300	900	300	300
2	300	12,000	500	2,000	500	
2½	500	20,000	1,500	3,600	1,500	
3	900	36,000	2,800	6,000	2,800	
3½	1,500	60,000	6,000		6,000	
4	2,000	80,000	13,000			
4½	2,800		18,000			
5	3,600		23,000			
6	6,000		37,000			
7	9,000		55,000			
8	13,000		78,000			
9	18,000					
10	23,000					
12	37,000					
14	55,000					
16	78,000					

	Drips to	
Steam Riser in.	Wet ret. in.	Dry ret. in.
1	¾	¾
1¼	¾	¾
1½	¾	1
2	1	1
2½	1	1¼
3	1	1¼
3½	1¼	1½
4	1¼	1½
4½	1¼	2
5	1½	2
6	1½	2½

TABLE 3. CAPACITY OF STEAM AND RETURN MAINS FOR AIR RETURN GRAVITY SYSTEMS—CAPACITIES IN RADIATION, SQ. FT.

Pipe Size, in.	Steam Rating	Wet Return	DRY RETURNS Main Return	Return Riser	Radiator Connections	Drips in.
½					50	
¾	20	800		200	100	
1	40	1,600	500	400	200	
1¼	75	3,000	1,000	800	400	¾
1½	150	6,000	2,000	1,500		¾
2	300	12,000	4,000	3,000		¾
2½	500	20,000	7,000	5,000		1
3	900	36,000	12,000			1
3½	1,500	60,000	20,000			1
4	2,000	80,000	27,000			1¼
4½	2,800		37,000			1¼
5	3,600		48,000			1¼
6	6,000		80,000			1¼
7	9,000					
8	13,000					
9	18,000					
10	23,000					
12	37,000					
14	55,000					
16	78,000					

TABLE 4. CAPACITIES OF STEAM AND RETURN MAINS FOR VACUUM SYSTEMS—CAPACITIES IN RADIATION, SQ. FT.

Pipe Size, in.	Steam Rating	BRANCH RETURNS Main Return	Return Risers	Radiator Connections	Drips
½				100	
¾	20	600	400	200	
1	40	1,200	600	400	
1¼	75	2,400	1,200	600	
1½	150	4,800	2,400		¾
2	300	9,000	4,800		¾
2½	500	15,000			¾
3	900	23,000			1
3½	1,500	37,000			1
4	2,000	55,000			1
4½	2,800	78,000			1¼
5	3,600				1¼
6	6,000				1¼
7	9,000				
8	13,000				
9	18,000				
10	23,000				
12	37,000				
14	55,000				
16	78,000				

TABLE 5. CAPACITIES OF STEAM DISTRIBUTING MAINS, WITH A TOTAL FRICTION OF 1 LB. FOR THE LENGTH OF RUN—RADIATION IN SQ. FT. UNWIN FORMULA—NOMINAL SIZES OF PIPE

Pipe	LENGTH OF RUN FEET							
Size, in.	300	400	600	800	1,000	1,200	1,500	2,000
4	3,300	2,800	2,300	2,000	1,800	1,600	1,450	1,250
4½	4,600	3,950	3,200	2,800	2,500	2,300	2,050	1,750
5	5,900	5,100	4,100	3,600	3,200	2,950	2,600	2,250
6	9,800	8,500	7,000	6,000	5,500	4,900	4,400	3,800
7	14,700	12,800	10,500	9,000	8,250	7,350	6,600	5,700
8	21,000	18,400	15,000	13,000	11,900	10,600	9,500	8,200
9	29,400	25,600	21,000	18,000	16,500	14,700	13,200	11,400
10	37,600	32,600	27,000	23,000	21,100	18,800	16,900	14,600
12	60,400	52,500	43,000	37,000	34,000	30,200	27,100	23,400
14	89,800	78,000	64,000	55,000	50,400	45,000	40,300	34,800
16	127,400	110,000	91,000	78,000	71,500	63,700	57.200	49,400

Calculated on the assumption that fittings, entrained water, etc., double the friction of straight pipe.

Maximum condensation of radiating surface and connected pipes taken at 0.3 lb. per sq. ft. per hour.

TABLE 6. SIZES OF HIGH AND LOW PRESSURE MAINS AND REDUCING VALVES FOR DROP APPROXIMATELY 1 LB. PER 100 FT. ON HIGH PRESSURE AND 1 OZ. PER 100 FT. ON LOW PRESSURE MAIN

High Pressure main, in.	Reducing Valve, in.	Low Pressure Main, in.	Capacity in Direct Radiation, sq. ft.
1½	1½x3	3	900
2	2 x4	4	2,000
2½	2½x5	5	3,600
3	3 x6	6	6,000
3½	3½x7	7	9,000
4	4 x8	8	13,000
4½	4½x9	9	18,000
5	5 x10	10	23,000
6	6 x12	12	37,000
7	7 x14	14	55,000
8	8 x16	16	78,000

Boiler pressure 30 lb. or over.

DISCUSSION

JAMES A. DONNELLY (written): The Committee that has been appointed to gather data on the standard of steam and return pipe sizes that are in use is interested in ascertaining what is a fair average of the best of present practice; not in what might be the standard, or what should be the standard, but in what *is now* the standard. They are not to create or establish a standard, but are to promulgate or set forth a standard.

A standard set forth in this manner is not intended as a fixed and unchanging guide. As laboratory and field research furnish additional information, the practice of our members will change accordingly, and the standard will need revision. It will thus be a standard which, following the best practice, will discourage any material variations from it.

The present standard of steam and return pipe sizes has gone through two distinct stages of development, and is now entering the third:

First—Empirical sizes founded solely on practical experience;

Second—The theoretical application of formulae of flow in developing a more rational comparative-carrying capacity, a logical ratio between steam and return pipe sizes, and a reasonably comprehensive method of rating the capacities of the various sub-division of the return piping;

NOTE—The formula that been used for determining return pipe sizes by flow and friction has been based on the assumption that mixtures of steam and water may be calculated on the weight per cubic foot of the mixture. So far as known, there have been no laboratory tests or field observations to verify this assumption, but it has been used as the most logical and only basis available for the calculation of flow and friction.

Third—Laboratory and field research to determine the critical velocities and a formula for the friction of flow of steam with moisture and condensate mixtures.

The practical standard of pipe sizes that is now used by the contracting engineer seldom allows for any factor of safety. The limit of load on the pipe is the approach of trouble. The consulting engineer and especially he who designs for the government or client of large means has almost invariably used somewhat larger pipe sizes, thus introducing a factor of safety against the poor quality of craftsmanship that is often unavoidable in public work.

Laboratory tests or isolated experiments on individual steam and return pipes will always appear to indicate that they have a much larger capacity than good engineering practice has ever conceded to them. The mathematical and mechanical problems of steam circulation, involving as they do both the individual and combined flow of three fluids, air, water and steam, are not easily investigated in the limits of a laboratory, but must have considered in their solution observations made in the larger plant installations. When this is done, the importance of the formula of flow in a single pipe will be found to be replaced by the results of practical experience, which has produced the frictional co-ordination of the complete piping equipment that must be established and maintained for acceptable operation of the plant.

As it may always be considered very difficult to construct a standard set of tables of steam and return pipe sizes that may safely be accepted for use without exceptions or modifications, it is very desirable to discuss some of the general or usual conditions encountered in their practical application.

There are two broad divisions that may be very definitely made in the subject of steam main sizes. The first covers the distribution of the steam, and the second its use. The conveyance of steam for any considerable distance is a problem by itself, needing separate analysis and altogether different handling from any of the problems concerning the use of the steam after it has arrived at the building to be heated. Steam flow tables should be used for distribution, and tables giving the capacities of steam mains and branches, radiator connections, etc., under standard or average conditions of use should be applied for sizing the pipes within the buildings.

The velocities of flow used in the distribution of steam are only limited by the available or allowable drop in pressure, while the velocities within the building where the steam is used are limited by the critical velocities or the velocities which will allow of sufficient separation of the condensation so that defective circulation or water hammer will not occur.

During periods of maximum load on distributing mains, the velocity of flow is often so far above the critical velocity that little, if any, condensation is withdrawn by the drips. At the ends of the runs and especially where the pipe sizes are smaller, the velocities used should be well below the critical velocity so that the condensate is completely withdrawn and not carried into the branch supply mains within the buildings.

There is no formula of flow available for estimating the friction drop of mixtures of steam and condensation or water primed from the boiler. Excessive moisture in the steam, or boiler priming, may so increase the drop in pressure that an entire failure in operation may result. It is, therefore, good practice to provide hand hole or equivalent cleaning means at the bottom of all boilers and a per-

manent surface blow for boiling off so that clean water and dry steam may be always maintained. It is quite probable that field research where boilers are priming would show a surprisingly high friction drop in the steam main.

It is to be hoped that the result of laboratory research will soon be available on the critical velocity in steam risers, radiator connections and laterals. In steam risers, there are probably two critical velocities, one in the centre of the pipe and one for water in contact with the side. With radiator connections and laterals, where the condensate is to drain in opposition to the steam flow, the influence of the number of elbows, length of connection and the pitch of pipe on the critical velocity, and, therefore, on the pipe size, should, if determined by accurate laboratory tests, be of great value.

Steam mains should not be dripped on the main trunk lines, and the riser connections and laterals pitched back to the mains. Much better results are obtainable by dripping the mains to take care of their condensation, and then pitching the riser connections and laterals to first floor radiators away from the main, and providing additional drips to take care of their condensation separately. In a carefully designed plant, no branch or lateral larger than the supply to a single radiator should be pitched back against the flow of steam and if it is not certain that the velocity is below the critical limit, the pipe should be provided with a separate drip. Water of condensation collecting in the laterals and surging up and down in the steam risers and radiator connections, is the cause of more poor circulation than any other single factor in pipe design. Its presence can usually be detected by the use of a tele-microphone or the application of a compound recording gauge, which will show an intermittent or jagged record of pressure.

The velocity of steam entrance to coils and radiators should be low in order that good air and water removal may be possible. Where the velocity is high, it is often necessary to insert a baffle plate to break up the entering jet and change the velocity head to static pressure. Steam type radiators with the inlet at the top and the outlet at the bottom, opposite end, or hot-water type radiators with a solid nipple between the first and second section at the top, will give the best results in efficiency of air removal. A hot-water type radiator not provided with means of breaking up the entering velocity of the steam will, when heating up, or when under fractional control, have a lower line of the heated surface which is not horizontal, thus showing the effect of the entering velocity and producing an inefficient air removal.

The question of low-entrance velocity of steam is especially important in connection with vento and hot-blast coils. The same practice should be followed as in air entrance to rooms for ventilation, where it is well known if the velocity is high the distribution of entering air is not uniform, and a poor removal of foul air is the result.

The separation of air and steam so that the former may be removed by an automatic device at the water outlet or by an air valve is only possible when the air and steam remain comparatively undisturbed by the entrance velocity so that they may stratify by gravity. When the entering velocity is too high, they become a whirling, vaporous mixture, impossible of separation.

F. D. B. INGALLS: I personally feel that there is a big opportunity for study of this question of pipe sizes. I believe this Committee ought to be somewhat of a clearing house to get the ideas from the other members in regard to the matter of pipe sizes, what their practice has been, and what their experience has taught them. There is quite a field for research in investigating the present formulae for determining such pipe sizes as are being used. I believe that most of our formulæ are based upon coefficients obtained from the flow of water rather than from the flow of steam. Also there comes the question which Mr. Donnelly again raises with regard to a mixture of steam and water, the presence of moisture due to priming in the boiler, and just how this affects pipe sizes. I may hold the opinion that our pipe sizes are abnormally large. Others may claim that they are a little bit too small. This all tends to the point that there is a field for investigation and research. I hope that it will be possible for me to co-operate with the Committee and Mr. Donnelly as far as possible. I believe that every member of the Society ought to feel himself a member of this Committee, at large, supporting the Committee in its work to the extent of giving the Committee his opinions and practices.

THE PRESIDENT: Is there any action to be taken by the Society on this report at this time, or is this merely a report of progress?

JAMES A. DONNELLY: I think it is merely a report of progress, to bring out the fact that these matters have been published in the Journal.

No. 562

REPORT ON STANDARD CODE FOR TESTING HEATING SYSTEMS

The proposal to establish a standard code for the testing of heating systems was presented as the result of an invitation received through New York Chapter from the Heating and Piping Contractors National Association, for the Society to develop and formulate a Code that may be accepted as a standard of the heating industry for the testing of heating systems of all types. The Standards Committee of the Heating and Piping Contractors National Association, in establishing a standard proposal sheet recently, has referred in connection with its specifications for testing heating systems, to the established standards of this Society, and the Officers of New York Chapter, realizing that the necessary data therefor are already existent in the Transactions of the Society, passed resolutions at its February Meeting that the work of collating and codifying these data be immediately inaugurated to meet this need. The Council accepted this recommendation and at a meeting on March 24, 1920, authorized invitations to be sent to all of the eleven Chapters of the Society for expressions of opinion to be sent to the 1920 Semi-Annual Meeting concerning the form which such a Standard Code should take. The recommendations that were offered by the various Chapters and the discussion which followed are here recorded:

ILLINOIS CHAPTER

John Howatt: Relative to the subject of codifying a method of testing heating systems, the writer is of the opinion that a different code for testing would have to be prepared for each different type of heating plant. The object to be arrived at in any heating system is the ability to maintain a certain specified temperature within the spaces to be heated under the most severe weather conditions that may be expected in the locality in which the plant is to be installed. The condition and exposure of the building makes so much difference in the demand on the heating system that a comparison of systems by their ability to heat certain spaces to certain temperature under similar outside weather conditions cannot be made. It would seem, moreover, that the heating and ventilating engineer should not be held responsible for the failure of a heating installation designed by him to properly heat a newly-constructed building if

extraordinary load is placed on the heating plant by reason of defective workmanship and construction of the building itself. It would be just as logical to hold the manufacturer of a boiler plant to a guaranteed overall efficiency of a steam-electric generating plant. Any scientific code, therefore, for testing heating systems should eliminate the ability to heat the rooms as one of the factors. Whether the heating system is a steam, water or hot-air system, the basic rule should be that the quantity to be measured is the heating units delivered to the room or space as specified, and a testing code developed upon this basis.

G. W. HUBBARD: In order to conduct a test of any sort, the object for which the test is made must be definitely known beforehand, so that it can be determined how elaborate the test must be. In my opinion, the best test of a heating system is whether it will keep the building at a comfortable temperature in climatic conditions for which it is calculated and installed. After the installation is completed, thermostats or other equipment which have to be adjusted should be put in proper adjustment and the boilers or heaters fired. An examination of the complete installation should then be made to see that all the equipment is operating properly and that radiators are heating approximately equally. If this is true, the system should be considered as complying with the general conditions surrounding the installation. Having done this, it should be unnecessary to make tests until the next season when if the plant fails to keep the building at a comfortable temperature this fact will be reported and it can then be determined whether the design or the installation of the the system is at fault, or whether the trouble is due to extraneous conditions. If there is no report of failure to heat or to keep the building at proper temperature, it can be considered that the design and installation are satisfactory. I believe a practical test as indicated above will be much less expensive in time and money to engineer, contractor and owner, and that it will show as much as would a more elaborate test under scientific conditions which would never even be approximated under the ordinary conditions of operation.

H. M. HART: Our practice in testing low-pressure heating boilers is as follows:

We hang a thermometer in each room, as near the center as possible, about 4 ft. from the floor. We then clean the fire, and fill the fire-box with coal. If it is a steam job, we set the diaphragm regulator for 1 lb. pressure; if it is a vapor job we set it at 4 oz.; if it is a hot-water job, we set it at 190 deg. We then make temperature readings for a period of not less than 8 hours, allowing the temperatures to run as high as they will in the rooms heated. After this we make due allowance for the outside temperature in order to determine whether there is sufficient radiation in each room.

The boiler is expected to maintain an average temperature of 190 deg. of water leaving the boiler on a hot-water job; to maintain an average pressure of 1 lb. on a steam job; and to maintain an average of 4 oz. on a vapor job, for this 8-hour period without stoking the fire or recoaling. There is also expected to be a good bed of coal at the end of that period for the purpose of re-firing. In other words, we expect our house-heating boilers to easily carry the load during the severest weather on 8-hour firing periods. On larger installations, where soft coal is used, we vary the firing period from one hour to four hours, depending on the size of the job and the character of the fuel. We then weigh the condensation, after making sure that the boiler is not foaming.

These are what might be called rough and ready methods of testing; but we find them sufficient for our needs, as we can readily determine from such tests, the cause of the trouble, if there is any.

J. C. HORNUNG: The capacity and efficiency of the heating system depends upon two fundamental considerations. The first being the design and installation of the plant itself, and the second, the construction of building which is to be heated. The design of the heating plant may be divided into two parts. The one having to do with the capacity of the boiler and radiation to heat the space within a given time, while the other has to do with the capacity and efficiency of the boiler to continue to heat the space under the variable temperatures. The matter of capacity for heating quickly should not be given first importance since it is apt to lead to excess capacity which for continuous operation results in lower efficiencies. This is especially so since the maximum capacity of the boiler is used only a comparatively short time during the heating season. The wall construction of the building to be heated is to my mind of greatest importance and should in all considerations leading toward the standardizing of equipment, be taken into account. As Professor Allen has done considerable work along this line, I should like to see further tests made at the Research Laboratory to fully develop and establish several variables and constants in connection with the relation of the heating equipment to the space heated.

LLOYD HOWELL: My suggestions on the subject of codifying a method of testing heating systems are as follows:

1. That maximum hourly steam demand be fixed per Standard for Computing Required Radiation adopted by the National District Heating Association at Pittsburgh last June;
2. That chimney dimensions and draft intensity conform to published data of the Thompson Heater Corp., of Buffalo, Copyright 1917, by C. B. Thompson;
3. That radiator sizes be apportioned per N. D. H. A. standard in (1).
4. That boiler capacity be proven by delivery under conditions above for the firing period and the fuel with rekindling reserve called for in specifications; that steam be maintained at 1 lb. pressure above atmospheric pressure; that steam delivery be determined by previously tested condensation meter or by accurate platform scale;
5. That all supply piping and radiators entirely fill with steam during a 20 minute period with 1 lb. pressure continuously maintained at the boiler and that complete and noiseless removal of air and condensate is simultaneously effected.

MASSACHUSETTS CHAPTER

The Committee of the Massachusetts Chapter of the Society which was appointed to make suggestions for a proposed test code has had two meetings to consider the matter. These meetings show that all of our members feel that the drafting of such a code leads quickly into very fundamental questions. For this reason we prefer to make our suggestions informally as in this letter and to indicate what the problems are rather than what the answer should be.

The following points seem to be pretty well agreed to:

1. *Scope of Code.* The Code should be a set of rules for testing particular pieces of apparatus and the Society would do better to thoroughly formulate the practice successively of such apparatus rather than to attempt too broad a scheme at the present time.
2. *Overall Guarantee of a Building.* The guarantee that a given system will heat a building to 70 deg. with a given outside temperature ought not to be encouraged by the Society. If the work is laid out by an engineer, the contractor should be held responsible only for quality of material and workmanship. The attention of the Society has in the past been chiefly drawn to this kind of guarantee, but it is felt that it is

not a guarantee which can be reasonably backed up by the Society or enforced in the courts.

3. *Economy of Fuel.* Care should be taken that any regulations adopted should not be such as to lead to an undue size of units and consequent waste of fuel in operation.

4. *Room Temperature.* In testing an indirect heating system where it is specified that the room temperature shall be a certain amount this temperature should not be the average temperature in the room. A better statement would be: "The temperature shall not be below the specified temperature at any point within a certain zone from 6 in. above the floor to 5 or 6 ft. above the floor. The zone shall not extend to within 2 ft. of an outside wall or window."

5. *Humidity.* Measurement of relative humidity should be made with a sling type of psychrometer rather than a stationary instrument. It might be well to state how many turns per minute is standard for a given length of the sling.

6. *Fans.* The fan or fans shall be tested for volume and pressure by the use of a standard pin-hole type pitot tube, as adopted by the Society, using an inclined manometer or U-tube, and using gasoline in the manometer for 1 in. or less, in making the proper corrections to take account of the specific gravity of the liquid unit; for over 1 in. water can be used. At least ten readings should be taken, both horizontally and vertically across the discharge or intake pipe, depending on whether the fan operates as a blower or an exhauster, and an average of all the readings taken should determine both the velocity and pressure under which the outfit is operating. The readings should be taken not less than 5 ft. from the discharge, and within 2 ft. of the intake. From the pressure readings and the size of orifice, the volume and static pressure can be obtained by simple calculations. Account should be taken of the temperature of the air handled and the altitude.

In no case is an anemometer to be used for testing the capacity of the fan or fans. It is only to be used for testing the distribution into the various rooms and through the various outlets. When used for this purpose, the orifice is to be divided into equal sections, and the readings taken from the anemometer for velocity are to be taken with the anemometer stationary. Proper allowance is to be made for the free area taken up by grilles, register faces, etc.

7. *Motors.* The motors for driving the fans are to conform to the specifications approved by the *American Institute of Electrical Engineers.* An increase of 25 per cent is to be allowed over the brake-horse-power consumed by the fan for obtaining the rated horse-power of the motor, where 50 deg. cent. motors are used. This factor of safety would take into account the belt loss and the slight variation which may occur in the volume of air handled, due to the possibility of less resistance than estimated. Where 40 deg. motors are used, an increase of not less than 15 per cent over the brake-horse-power required by the fans is necessary. The above shall also apply to direct-connected motors even though the belt loss be eliminated. Where belts are used, motors should be furnished so as to maintain a ratio between fan speed and motor speed of not more than four to one, preferably less.

8. *Heaters.* Where cast-iron indirect heaters are used, they shall be tested to a hydrostatic pressure of 100 lb. per sq. in., before and after assembling, and operated on not more than 40 lb. per sq. in. Where pipe coils are used, each section shall be tested to 150 lb. hydrostatic pressure, and operated on not to exceed 100 lbs. The loss due to resistance through the heater is to be kept as low as good practice will permit, and in no case is it to exceed 0.75 in. of water.

9. *Washers.* The washer shall be so constructed as to be practically noiseless. It shall remove not less than 95 per cent of all dust, dirt, soot,

and other impurities which are in suspension. Some sort of test for the washing effect should be devised.

COMMITTEE OF MASSACHUSETTS CHAPTER.
ARTHUR E. NORTON, *Chairman.*
DAN ADAMS.
H. W. PFEFFER.

MICHIGAN CHAPTER

J. R. McCOLL: I am enclosing herewith an outline of tests on heating systems, which was drawn up rather hurriedly, and is intended to cover furnaces, steam systems and hot-water systems. I presume that stoves for heating would not be called heating systems and that you had no idea of including tests for these.

HEATING UNIT:
1. Combustion. (Design data.)
   (a) Grates and fire chamber;
   (b) Flues and gas passages for good combustion;
   (c) Chimney and breeching.
2. Heat exchange. (Design data.)
   (a) Heating surfaces, direct and indirect;
   (b) Flue gas passages for heat exchange;
   (c) Means of keeping surfaces clean.
3. Combined efficiency of furnace and heat-absorbing unit.
   (a) Test data to determine what percentage of heat of coal is actually delivered from boiler, water heater or furnaces to piping or duct system.

CIRCULATING SYSTEM:
1. Design.
   (a) Supply system to deliver steam, hot water or hot air as required.
   (b) Return system to return condensate, water or recirculated air as required.
2. Installation.
   (a) Quality and durability of material.
   (b) Quality of workmanship.

AUXILIARY UNITS:
1. Supply fans used in heating.
   (a) Capacities, speeds, horse powers, etc.
2. Indirect radiators.
   (a) Type, size, connections, arrangements, air distribution through them, air removal and type of control.
3. Direct radiators.
   (a) Type, size, location, connections, air removal and type of control.

HEAT LOAD:
1. Radiation losses from building or room;
2. Requirements for heating up in morning;
3. Heat required to take care of leakage;
4. Requirements for heating any air supply.

EASTERN PENNSYLVANIA CHAPTER

Your committee to make suggestions regarding what should be included in the standard code for the testing of heating and ventilating plants believes that the needs for such a Code is obvious and requires no discussion.

The scope of this committee's work is not at all to attempt the formulation of a Code, but to present to the Society suggestions which may be of assistance or value in the formulation of this Code. Perhaps all of the suggestions in this report have been previously brought before the Society in papers and discussion, as free use of the proceedings has been made. The list of references is included below and consideration of the articles referred to in their entirety is earnestly recommended in formulating this Code.

1. *Condition of Building*: The building in which test is made should be in the condition, as near as possible, that prevails when apparatus is in use. It would seem desirable to define specifically the condition of the building as far as occupancy is concerned. That is, whether a church, theatre, or a building used for assembly purposes generally, is to be tested or not when occupied. It is, of course, not always possible to make a test under these conditions, but it would seem worth while to define this condition exactly. In other words, whether or not the generated heat from apparatus or occupants be allowed for, or not.

2. *Time*: Before the test is started the apparatus should be operated continuously a sufficient length of time to insure normal working conditions.

3. *Operation*: During test the apparatus should receive the same care and attention it will receive during normal working conditions.

4. *Duration*: Length of time for test should be 8, 16 or 24 hours and repeated one, two or three times to cover extreme (day or night) conditions.

5. *Observations*: Records of pressures, temperatures, humidities, velocities, etc., should be taken at extreme points and averaged, or at central or fixed locations as specified, a standard of maximum or minimum radiation should be considered.

6. *Results*: The average and maximum results of tests may be reduced to equivalent results under changed conditions, by reference to tables or chart to be standardized by the Society.

7. *Window Leakage*: It would seem desirable to adopt a standard basis of window leakage basing this leakage on definite maximum velocities. Some engineers have inaugurated a practice of indicating on the plans the number of air changes for which the heating surface is figured. Any contractors or engineers who have suffered on account of a badly made and leaky sash would appreciate the necessity of limitations of air leakage. There has been much literature published on this subject and it is thought that this leakage should be defined in its relations to the area or perimeter of the sash, rather than be expressed in dimensions of the contents of the room.

8. *Testing Air*: The method of testing air delivery or exhaust for air supply and ventilating system should be defined. It is suggested that the pitot tube be used as a basis in determining the total delivery, using this instrument near the fan or in large branches where the velocity is sufficiently great to justify its use, and that the anemometer with the recognized difficulty of securing accurate results from it, be only used to proportion the delivery of various registers. The method of using the anemometer should be definitely defined. Whether or not there should be any allowances made in this reading for the obstruction of the register bars might also be definitely defined in the report. Performance of fans during test shall be pro-rated to specified conditions.

9. *Need of Standard to be Referred to by Contractors*: It is thought that this Code should define also test conditions for house heating and other work where the specifications are usually very meager, and perhaps it would be an advantage to divide the Code up into sections to fit different classes of work, starting with the small house-heating job and pro-

gressing to the most comprehensive installations. For the smaller jobs, the chimney draft to be obtained and the combustion rate should be defined. For hot-water systems, the maximum temperatures of water, for steam systems the pressure under which the test is to be made, should be defined.

The circulation with steam, water or vapor with the definition of the time required to secure circulation throughout should be taken into consideration. The permissible temperature drop between the supply and discharge on water radiators should be defined.

10. *Air Conditioning*: The physical condition of air would seem to be a pertinent part of this Code and should have a place.

11. *References*: Following are some references to which attention is invited.

Temperatures for Testing Indirect Heating Systems, by Wm. Macon, Transactions, Vol. 13, 1907, p. 74.

Report of Committee on Radiators, by J. A. Donnelly, Transactions, Vol. 18, 1912, p. 303.

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COMMITTEE OF EASTERN PENNSYLVANIA CHAPTER,

R. C. MORGAN, *Chairman*.
W. G. R. BRAEMER.
J. D. CASSELL.
A. C. EDGAR.
A. T. LEWIS.

WESTERN NEW YORK CHAPTER

L. A. HARDING: The time-honored and ancient custom of copying that which is thought to be good practice in specification writing has unfortunately developed among many others, a paragraph relating to the artificial warming of a building which most Contractors will admit has failed to appeal to their sense of humor. This paragraph generally reads in substance as follows:

"The Contractor shall guarantee the heating apparatus to heat the building to a uniform temperature of 70 deg. in zero weather."

This, it will be agreed, is some job, particularly when it comes to warming up the glass to 70 deg., but by a mutual understanding of all interests concerned, it is generally interpreted by the Owners' representative, that it is the air inside the building that is to be warmed and not the building. This point having been conceded the only thing necessary for the Contractor to do is to patiently await the one day when he will be allowed, on short notice, to hustle out to the jobs that he was unfortunate enough to get in open competition and run the official test or trial, in accordance with his best judgment, knowledge and belief that he is giving the Owner a little the best of it. The most generous concession made by the Owners' representative is that the Contractor be allowed to use his boss steam fitter's thermometer and if there are no ill winds a perfect specification day draws to a close with gratifying results to the most interested party.

In order to avoid any misunderstanding as to the exact method to be employed in running the above test, the Heating and Piping Contractors National Association have proposed as part 6 under the heading—Conditions of their standard proposal sheet, that the test shall be made by the Contractor under standards established by the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS. But the Society has not as yet established any such standards, although there have appeared from time to time formulæ and tables purporting to give one the necessary information as to what inside temperature should be maintained when the system has been installed as per specifications and is to be tested under outside temperatures and conditions other than those specified. The following assumptions are of necessity made when formulæ for equivalent temperatures are assumed to hold good:

a. The heat emission of direct radiation is directly proportioned to the difference between the steam temperature inside the radiator and the average temperature of the air surrounding the radiator;

b. The heat transmission loss of the room or building is directly proportioned to the difference between the inside and outside air temperatures;

c. The weight of air entering by infiltration in unit time is a constant regardless of the inside and outside temperatures and wind velocity.

The (*a*) and (*b*) assumptions are sufficiently accurate to warrant their adoption and use. The weight of air entering by infiltration, however, is generally conceded to be some function of the outside wind velocity and is not by any manner of means a constant. The so-called heat loss by infiltration is therefore a varying quantity and as it is generally a large percentage of the total loss of heat "c" assumption is not warranted. It is common knowledge among the heating fraternity that a combination of high-wind velocity and a higher temperature than that for which the system was designed, may put a greater tax on the heating system than the lower temperature specified for the test.

The equivalent temperature formula for the direct heating referred to is as follows:

Where

t = inside temperature for which system is designed;

t_0 = outside temperature for which system is designed;

t' = equivalent inside temperature to be maintained during test;

t'_0 = outside temperature during test;

t_s = temperature steam inside radiator;

h = heat emission of radiator per hour per degree difference temperature between t_s and inside air temperature (t or t').

H = heat loss from room or building per degree difference in temperature between inside temperature (t or t') and outside air temperature (t'_0 or t_0).

$(t_s - t)h = (t - t_0)H$ (1) specified condition, and

$(t_s - t')h = (t' - t'_0)H$ (2) test condition.

Dividing equation (1) by (2) and solving for t'

$$t' = \frac{t_s(t'+t-t_0) - t\,t'_0}{t_s - t_0}$$

For example: Required the equivalent inside temperature for the following conditions: $t = 70°$, $t_0 = 0°$, $t_s = 220°$, and $t'_0 = 30°$.

$$t' = \frac{220\ (30 + 70 - 0) - 70 \times 30}{220 - 0} = 90.4.$$

A test run under the condition imposed by this formula is only a test on the amount, or of direct radiation installed and is not a comprehensive capacity test, covering the boiler, piping and chimney. To illustrate this by the previous example, assuming that an inside temperature of 90.4 deg. was maintained during the test.

The load carried by the radiation and boiler would be, expressed as a decimal:

$$\frac{220-90.4}{220-70} = 0.864$$ or 86.4 per cent of the equivalent specified load the apparatus must carry when operating at specified conditions. The boiler could, under these conditions, be 15 per cent smaller capacity than should be installed to fulfill the guaranteed conditions and still fulfill the condition imposed by this method of acceptance test. The same statement applies to the pipe sizes, chimney sizes and other component parts of the system.

This is therefore not an entirely satisfactory method of test as it only informs us whether or not there is a sufficient amount of radiation installed to meet the guarantee. A better method, if an equivalent temperature test is to be used, would be to require that an inside temperature be maintained during the test, which will give the same total heat transmission loss that would be obtained if the test were run under conditions of the specified guarantee. This temperature would be the product of the actual outside temperature and the specified temperature difference between the inside and outside air, or $t' = t'_0(t - t_0)$

In order that the radiation emit and the boiler supply the same amount of heat as under specified conditions, the temperature difference between the inside air and the steam in the radiator must be the same and as the room temperature maintained during the test will be higher than the specified temperature, the temperature in the radiator must be raised to an amount equal to the sum of the room temperature to be maintained, plus the difference between the specified steam temperature and specified room temperature, or $t'_s = t' + (t_s - t)$

Assuming the same data are in the preceding example. The room temperature t' to be maintained during the test would be:

$$t' = 30 + (70-0) = 100 \text{ deg.}$$

and the corresponding steam temperature to be maintained would be:

$$t'_s = 100 + (220-70) = 250 \text{ deg.}$$

corresponding to 15¼ lb. gage pressure at the radiators.

This scheme, although theoretically correct for steam systems, is not very practical when the test is to be run at any outside temperature much above 20 deg. as the pressure becomes excessive for low pressure installations, and is 10 lb. gage for this temperature. This scheme is of course not applicable for testing gravity hot-water systems.

It does not appear that any scheme of testing under so-called equivalent temperature conditions is an entirely reliable and satisfactory method of determining whether or not a system does fulfill the guarantee due to a multitude of varying conditions over which neither the Contractor nor Owner has any control. The design of any form of heating system should naturally be the controlling factor of all specifications relating to the subject. If the design is right, for the conditions imposed, then a temperature test is superfluous, although a steam circulation test should of course be made.

Enough reliable and proven data are at hand, for those who care to make use of them, to satisfactorily design the present type of systems in use to meet all reasonable conditions.

It is not here inferred or assumed that exact data as to heat transmission of all building materials are at hand or ever will be available, due to the fact that building materials of like kind vary in structure and density to an extent that exact data cannot be obtained, as for example: covering the products of every brick and tile plant in the country. The heat loss due to infiltration is not and never will be estimated in advance with exactness due to variations in the character of the workmanship, materials employed etc.

The fact remains, however, that systems are installed that prove entirely satisfactory as designed by the accumulated data at hand. The performance of radiation and boilers, pumps, fans and other heating accessories for the rating conditions under which they are at present sold, is well known and accepted by the engineering fraternity. It simply remains to fit the available data on the apparatus to our varying conditions.

It would appear that the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS could, without the expenditure of very much grey matter, sanction a Code comprising a series of tables, covering requirements as to heat transmission losses, losses due to infiltration, heat emission of radiation, pipe sizes, etc., and brief standard specifications, covering the installation of various systems of heating. This code will necessarily be revised from time to time as all other codes established by engineering societies and municipalities are revised to incorporate new and more reliable data.

If the Society is to put off the day until a perfect code or codes are evolved then none will ever emanate from this body and every city will eventually have its own, more or less complete heating code. These building codes are not in accord even as to the simple requirement of design stresses for materials of construction. There is more reason why a fixed size beam is not just as safe under certain conditions of loading in Buffalo as it is in Cleveland, but according to the two building ordinances, it is not, and the same condition will arise as to the rating of heating apparatus.

N. LORING DANFORTH: I like to think of the Owner, the Architect and the Contractor in their relation to each other, as a trinity of power, brought together through the medium of a contract for construction work, which may be compared to a three-legged wireless tower. Properly supported on its three legs, the complete tower functions properly and stands

as a symmetrical and artistic structure, with each leg carrying its part of the load. Destroy any one leg, and the other two are helpless, the tower toppling over. Let any two of the three parties referred to, try to function without the third, and, we find as a rule an economic loss. Occasionally the Owner does business direct with the Contractor, excluding the Architect, and less often the Owner and Architect try to build their structure without the Contractor. Never could the Architect and the Contractor exist without the Owner, except of course the Architect or the Contractor who builds a house for himself.

If this three-cornered relationship between the owner, the Architect or consulting engineer can be kept in mind, for I shall consider these two simultaneously as coming in the same class (the consulting engineer being really an architect who is skilled by training in engineering construction) and the heating contractor as the third party, I shall endeavor to discuss their relations to each other, their common problems and perhaps correct some wrong impressions gained by one in doing business with the other, these wrongful impressions being due more to a misunderstanding of common problems, or perhaps to a lack of breadth of vision, than to any serious defects.

First, the Owner: Of the troubles of Owners and Architects 90 per cent encountered in the installing of heating systems today are due to poor plans and specifications. So many Owners make the mistake of buying a heating plant upon the wording of a guarantee that the plant when completed will do certain work—let us say "to heat certain rooms in a house to 70 deg. in zero weather." We heating Contractors are not in business to sell guarantees. Our business is to buy and sell pipe, fittings, valves, radiation, pipe covering and the labor to install these materials, and last but most important we sell our brains and our experience, in putting all these articles together into an efficient heating plant. How absurd then, it is for Owners to buy heating plants, where each bidder bases his estimate on a different amount of radiation and boiler and pipe sizes from his competitor. The owner takes the lowest bid, finding refuge in the old clause "70 deg. in zero weather"—congratulates himself on having a low price, and then complains later when he finds he has installed a cheap plant, the very principle of price competition forcing the low bidder to cut his estimated radiation requirements to the lowest possible notch to get the order. So the Owner first of all should realize that when he buys a heating plant, he is not buying guarantees, but is buying definite quantities of materials, and that the only way for him to really compare competitive bids is to have all bidders estimate on the same layout.

The heating Contractors should decline to bid on heating jobs except where the plans and specifications are clearly and carefully drawn by an Architect or consulting engineer. The larger Architects do pretty well in this regard, but the smaller ones are woefully weak. Their defense is that their commission isn't large enough to enable them to employ a heating engineer, and so they either attempt a layout, or else they employ a favored heating contractor to lay out the work for nothing, on the theory that the gross amount of business warrants asking and granting the favor, or perhaps granting some especial favor after the bids are opened. In either case, the Architect is getting something for nothing, or the Owner doesn't obtain real competition because other bidders are *not* apt to offer their lowest prices under such conditions. If the local chapter of Architects would agree not to send out plans and specifications for heating unless same were fully complete, I assure you that heating Contractors would reciprocate by refusing to figure heating jobs which were not laid out.

We Contractors have long been opposed to having the boiler and radiator manufacturers make heating layouts. We believe this work belongs to the Architect or consulting engineer. Except for the larger firms, most heating contractors are not equipped to do engineering—and where

the larger firms do go in for engineering, they should make it a separate part of their business, charging for such plans and specifications a proper fee, separate and distinct from any possible future contract, and so run this department as to insure to their clients the same competition which they would secure from an Architect or consulting engineer.

Owners entering into contracts should specify reasonable terms of payment, and should conscientiously meet these payments as they come due. The Architect should co-operate in this matter. Nothing destroys the contractor's confidence in and friendship for the Owner and Architect quicker than an attempt to cut a proper request for money—or attempt to put off or evade the final payment. The larger the job the less should be the retained percentage, particularly if a bond is required. Everything we buy these days has to be paid for in 30 days; the larger concerns have to meet their increased overhead by discounting their bills, and we pay our invoice in full—not 85 per cent, which is the payment we take from the owner. The Architect answers that he is not sure of the financal strength of the Contractor. My answer is not to allow Contractors to bid on work unless satisfied that all bidders are financially responsible and that the job will be given to the lowest bidder."

Owners should refuse to do business with the Contractor who is financially unable to swing the contract. So often, Owners are asked to guarantee payment of a bill of materials bought from a jobber or manufacturer by the heating contractors who has not sufficient credit to buy what he needs on the usual terms. It is this practice which constantly brings into the business the mechanic without capital with no overhead and without the experience needed to do good work. The owner thinks he can save something under the price of a reputable contractor regularly engaged in the business. Materials sold on shaky credit are not sold close and this kind of work generally costs more money in the long run.

Second, the Architect: We shall assume the specifications and plans are to be complete and I will cite a few "Don'ts."

DON'T specify outright, without competitive makes, some one boiler or radiator. It is no more fair to your owner than if you specified: "This heating contract will be awarded to the Danforth Company regardless of all competition." Nothing is so good in this world, that "the other fellow" doesn't make something just about as good.

DON'T specify side by side two articles which everyone knows are not equal in price or quality. And don't use the words: "or *equal as approved by the architect*." If you don't know the other things that *are* equal, when you write the specification, how are you going to know later, when the contractor is urging the substitution of some other make or material.

DON'T approve the contractors' detail drawings and then plead later that you didn't understand them, and be forced to seek refuge behind general clauses requiring a complete and satisfactory working plant. The successful architect is one who *meets* responsibility instead of trying to shift it onto someone else—who makes decisions promptly, holding the contractor to his just responsibilities, and stopping there.

DON'T write an elaborate specification carefully describing with its accompanying plans, a heating system, showing boiler size, radiation, pipe sizes and all details, and then wind up your specification with this timeworn, moth-eaten, clause generally reading about as follows:

"When the plant has been completed, the contractor must guarantee it will heat all rooms in which radiation is placed, to 70 deg. in zero weather, and shall make such changes as are necessary to produce these results, without expense to the owner."

I believe the Owner and the Architect have a perfect right to call for a guarantee of this character providing the *contractor* designs the plant in

detail, without suggestion from the architect. I also believe that it is perfectly proper to put into a specification a guarantee calling for a job to be workmanlike and tight when completed—that a steam job should circulate steam properly without water-hammer due to pockets or improper grading—or for a hot-water job to circulate properly without unbalancing or sluggishness, when the water leaves the boiler at say 180 deg. But if the Architect's plans show piping details which will not produce these results, even if installed in a workmanlike manner; or if the radiation specified for a given room is not sufficient to produce 70 deg. in zero weather, there is no excuse for the Architect attempting to shift his mistakes onto the heating Contractor for him to make good at his expense.

In these days, figuring heat losses through building materials, and calculating the necessary radiation has been brought down so nearly to an exact science that the margin of error is small—especially if a reasonable factor of safety is allowed in selecting the size of the boiler.

DON'T be touchy and show a spirit of mistrust when the heating Contractor suggests a change in the layout which will improve the job. If you treat him right he should be more than willing to apply any saving he might make to some other part of the job where you want something extra with no money to pay for it, and give him credit in suggesting changes which really do improve the original layout. The really big men in this world are those who are always ready to listen to criticism and are willing to take suggestions from others and weigh them carefully without resentment and without prejudice.

DON'T put into your specifications the old worn-out clause: "The architect is the sole and final judge of the interpretation of the drawings and specifications and his decision shall be final and binding on all parties," etc., etc. Neither of the two parties to a contract can be the *sole* judge of the other and take away his legal rights. This brings me to my last suggestion to Architects and Owners alike, and that is that all contracts should contain an *arbitration clause* for settling disagreements. A board of arbitration is much cheaper and more prompt in rendering a decision than any court of justice—and usually should be a more friendly operation than court proceedings. Please understand that an arbitration clause in a contract *cannot* take away the right of either party to a court review of the question at issue. But it has this advantage: The party who loses his argument before an impartial arbitration board is apt to think twice before plunging both parties into a court proceeding.

Third, the Contractor: Never was it more difficult to take lump-sum contracts than at the present time. The material market is fluctuating but the tendency is toward lower prices. Skilled labor is stationary with strong possibility of lower wages; common labor is much lower.

Personally I believe, in these uncertain times, that the Owner and Architect should be encouraged to let contracts on the basis of cost plus percentage for overhead and percentage for profit—or *cost plus a fixed fee*, if the magnitude of the operation can be approximately determined. If the contractor is reliable and has a good organization, the labor costs should not differ materially from those on lump-sum contract work. If the Contractor is honest, the Owner gets the benefit of the saving made in purchasing material below estimated costs. The vexatious problem of adjusting extras is disposed of, with all the wrangling and hard feeling which unconsciously results from a big bill of extras and if the work is handled right by a reputable contractor he can afford to do it on less gross profit because he has no risk. The result is a saving to the Owner on the total job.

The Heating and Piping Contractors National Association recently adopted a set of uniform conditions, to be made a part of all proposals

for heating work. In view of what I have already said, the necessity for most of these clauses will be readily appreciated. They are as follows:

1. Sufficient space shall be provided on the premises by the purchaser for the material and for the proper prosecution of the work;
2. All labor and material required to complete the work not included in this proposal, shall be provided by purchaser in such manner as not to delay the progress of the work;
3. The purchaser shall provide a chimney of proper dimensions and draft for the apparatus proposed herewith;
4. All cutting through floors or walls for the installation of this work, and finishing around same after work is completed, shall be done by the contractor, unless otherwise provided in contract;
5. The contractor will guarantee the installation against original defects of material and workmanship, for a period of one year from the date when the apparatus is ready for practical use, and agrees to replace, without expense to the owner, any part requiring replacement within that period, due to inherent defects of material and workmanship. Contractor's liability in this matter extends only to the labor and material furnished, and does not cover any contingent liability, either to buildings, contents, products or persons;
6. If the work comprehended by this proposal covers the installation of material and apparatus under specifications made by others, the performance liability is not assumed by the contractor. Should the contractor guarantee temperatures or operation of this system, and tests be required, such tests shall be made by the contractor under standards established by the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS;
7. If upon completion of work, weather or other conditions over which the contractor has no control, do not permit of a proper test, this shall not be considered a sufficient reason for witholding payment;
8. This proposal is based on the prevailing rate of wages and the execution of the work during regular working hours;
9. The contractor shall not be held liable for delays, strikes or causes beyond his control;
10. Title of ownership of all apparatus and material furnished under this proposal shall remain with the contractor until final payment is made, and the contractor shall have the right to remove same, should default in payment occur;
11. Unless special terms are made at the time of entering into contract, it is understood that payments of 90 per cent monthly of the value of materials delivered, as well as labor performed, are to be made, and the balance paid on completion;
12. Any dispute arising under a contract based on this proposal that is not settled within thirty (30) days, shall be referred to two arbitrators, one selected by each party to the contract. Should they be unable to agree, they shall select a third arbitrator. The decision of a majority of these arbitrators must be given within sixty (60) days from the date of reference, and shall be binding on both parties to the contract; one-half the cost of arbitration to be paid by each party to the contract.

My discussion of this three-cornered relationship between the Owner, the Architect and the Contractor, may be summed up in those old familiar words: "Do unto others as you would have them do unto you." A little less of contract law and a little more of the golden rule, practiced liberally, would bring us all closer together. Let us have more confidence in each other, for confidence always leads to co-operation.

C. W. FARRAR: There should be formulated, at this time, a standard code for testing heating outfits, especially for residences, stores and standard building work. The demand for this is imperative and architect's specifications in many cases are so written, that this request for standardization is evident.

The reason for speaking here of house heating and small work, is that the specifications written for these types of operations are so minute and so vague, that it would be a benefit to the owner, architect and heating contractor to be able to state "install system to agree with the practice established by the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and equal to test of their standard code." The call for this standard installation and test would eliminate the guess work on such specifications as these: "Install boiler of ample capacity and place where shown on plan; connect this heater to radiation shown on plan, which is to be sufficient to heat the rooms to 70 deg. inside with outside zero." This example is not overdrawn. In fact, there appeared in specifications in Buffalo a few weeks ago, for a good size building, and of the type that required considerable thought when it comes to heating, the following:

"Contractor shall furnish sufficient radiation to heat building to 70 deg., and the boiler should be 100 per cent larger than direct radiation."

No mention was made of boiler capacity needed or desired, not even of the placement of the boiler in the cellar, nor main sizes, nor type of system required; also no placement of radiation or capacities needed for rooms was shown. Still the test of 70 deg. temperature inside with zero outside was to be made before final payment, and the contractor had to install material to meet the test, regardless of incomplete specifications.

It will be noticed that in both cases the specifications called for one standard prescribed condition: zero outside, 70 deg. inside. During the winter of 1918-19 (two years ago) the weather in Buffalo never dropped to zero; five above was the lowest and that was reported in January. This last winter also did not afford any lengthy periods of zero temperature. In fact, the average winter temperature in Buffalo is between 20 and 30 deg. above zero.

Mindful of these temperatures, it would seem that we could erect a curve or curves which will prescribe different inside temperatures, which could be created during the test, when the outside air is not zero, but say from 10, 15 or 20 deg. above. Entirely disregarding air direction and velocity, it may be possible to only test to say 15 deg. above zero on account of the radiator temperatures being too high and not maintainable at high temperatures on a low-pressure system.

The testing of equivalent temperatures must take into consideration the fact that the outside air movement at temperatures higher than zero are apt to be of greater velocity than still zero air. Could not a curve be created that would simply indicate the inside conditions with reference to the temperatures of the still air and the radiator surface which must be created to parallel—or offset—the upward differences in temperature from zero? Naturally, we will agree that the wind velocity likely to occur with temperatures higher than zero would constitute a serious error on such curve. It is my belief that a curve of this character could be created, taking into consideration and assuming certain conditions.

If testing of heating operations could be made on a range of outside temperature, of say, zero to 15 deg., it would greatly benefit the contractors, and would be a step forward in the right direction. It seems perfectly possible when boilers are rated, pipe sizes and capacities given, radiator footages established, and heat transmission of different building construction is figured. Therefore, it does not seem impossible to assume that a standard code for testing heating plants at equivalent temperatures from zero to 15 deg. could be established.

DISCUSSION

THE PRESIDENT: If we are to recommend a Code for the testing of a heating installation, it appears to me that it is only a question of restating standards that have already been plotted at the present time, as the testing of the boiler and the various parts of the equipment, have already been standardized to a great extent.

C. W. FARRAR: At the Heating Contractors National Convention at Cleveland, one of the largest fitters of the country told me that such a Code should be formulated immediately. I can see the particular reason for it. I believe that if it is possible to draw up a code and get that Code established, one may be formulated that will be used with a small amount of writing. I do not believe a code should be made so long and hard to follow that it would be difficult to keep up to standard.

H. H. HUMPHREY: Such a code should be adopted and it should not be necessary to go into boiler operation tests or the details of including the standard specifications for boilers, motors, pumps, fans, etc., which go to make up the heating and ventilating apparatus. Naturally, the pressure of steam would affect the operation of the apparatus and there should be some standard specification covering either so-called high-pressure or low-pressure steam. A Code is certainly needed for testing ventilating apparatus, not only in schools, but in hospitals, stores, hotels and buildings of all kinds. A committee should be appointed, made up of the directors of this Society including engineers and college professors. Such a committee would draft such a code and could accomplish it very quickly within the coming year, if it did not go into and include boiler code and electric motor specifications, etc., trying to cover too much ground. It should confine itself solely to the subject of heating and ventilating.

JOHN HOWATT: It seems to me the first thing to be determined before establishing a Code, or starting to establish a Code, is the object of the test. In neither one of those recommendatons as read was there a statement as to the object of the test, or what was to be determined. What is meant by a code covering the testing of heating plants? Is it a test of the amount of coal required to deliver a unit of heat by air, water or steam in the room to be heated?

J. R. MCCOLL: It seems to me that the question of heating and ventilation should be separated. If it is indirect radiation or direct, the quantity of heat, and guarantees to take care of the building losses should be separated from the requirements for ventilation.

THE PRESIDENT: There is usually a heating guarantee, isn't there?

J. R. MCCOLL: Yes.

THE PRESIDENT: Is there a ventilation guarantee?

J. R. McColl: Sometimes, but not often. It is usually written as the number of cubic feet.

Charles R. Ammerman: As to establishing a code for testing ventilating equipment, a report is to be presented later on standards of ventilation. Isn't it necessary to establish the standards of ventilation, before adopting a Code for testing them?

A Member: In order to bring this matter properly before the Meeting, I move that a committee of five be appointed by the President to outline a Code for the Testing of Heating Plants.

H. M. Hart: I think we would of necessity call for a standard form of guaranty and I don't think the heat given off by pipe or radiator would necessarily have to enter into this test, but it would have to be a method of standardizing the conditions of the test. In other words, the air change is not the main thing. I can see that this is going to be a big problem, because it gets right into the problem of building construction. An architect may write a specification that the heating contractor shall guarantee to heat the building to 70 deg. in zero weather. He won't say what the walls are going to be made out of or whether there shall be a single or double glass, and he doesn't give you any more information than he has to After he has let the heating contract the house construction may be entirely changed. That has been the case and has resulted in failure of the heating apparatus; so that this committee is going to have a problem before it.

Fred R. Still: I think what Mr. Hart says is true; we are confronted with some practical conditions that we have to meet. I can hearken back to the early days when there wasn't nearly as much understanding between the contractors and architects as there is to-day. I do think a definite standard should be adopted, not only determining where a thermometer should be placed, but also as to the noiseless operation of radiators and the ventilating apparatus. Another important factor is the adoption of a table giving the temperatures which a heating plant should attain in a building where it is designed for an outside temperature of zero, but the outside temperatures happens to be above or below zero when the plant is ready for testing. Provision should also be made for a basis in other climates where zero weather is unknown.

This can be done by the Research Laboratory as it only involves a lot of mathematical calculations. When done, it will become a standard which will be indisputable.

The President: Possibly it might be well to advise the committee as to what they shall not do as well as what they shall do. For instance, from the substance of the letters, from the various Chapters it would be desirable to outline the method of using a certain tool and that is purely outside the province of the Committee, for it belongs to the Research Laboratory entirely. I think Mr. Hart struck the key

note correctly when he said that we must start with the heating contract as per specifications. If that is done, the committee will be in a position to outline the best method to demonstrate the specifications or guarantee the contractor.

C. W. FARRAR: From what Professor Allen states there is no code of any kind at all, and it seems to me the establishment of this code is not a long, laborious job. I know that some members think this is a big undertaking; but we have most of the figures for the testing of radiation to a certain extent, so all this can be put in the code. Dr. Hill's suggestion is good, that the entire heating plant be taken in a small way, so that the average commercial men can install and perform the test. All the common specifications to-day written by the architect, call for a test at zero. Now, if there is a test arranging a temperature relation that can be worked out from zero to 15 deg., it would be a very splendid asset.

THE PRESIDENT: The inside temperature change is about half as fast as that outside. I would like to have some suggestion as to the members of this committee; Mr. Harding and Mr. McNair have been suggested, but I would like to have some more. I think it is important work and I realize its value, but I think it is a very difficult proposition, therefore, I would appreciate suggestions.

A MEMBER: I suggest Mr. Charles Lamb for the Committee.

A MEMBER: I would suggest Mr. Milliken.

E. E. MCNAIR: I have heard this question discussed for the last 20 years in Heating Contractors' conventions; the discussion always centers around this question: The contractor takes a contract for heating a building to 70 deg. in zero weather and completes the contract, say in August. Upon completion of the work, he wants a settlement and the owner withholds settlement until a zero day in winter when he can test out his heating system under the contract requirement. It is to cover such cases that the demand has arisen for a code under which a heating system could be tested on completion of the work whether in August or later in the season. The contractors have never been able to provide such a code and now are asking the Society to provide it. I would suggest for the President's guidance that several heating contractors who are members of the Society, be included on this Committee.

A MEMBER: It is usually the practice of engineers in making plans and specifications not to call on the contractors for any such guarantees. Then, why should we, as heating and ventilating engineers, make such a code to test this?

F. R. STILL: I think the opposite side of this is, how are the heating and ventilating enginers going to earn their fees, if they don't have anything to determine the result. For a great many years we used to do contracting. We had to take contracts for everything, in order to sell even a little fan. Later we entered into the manufacturing side of it, and acted as consulting engineers, then we stopped

the consulting service and adhered strictly to manufacturing, and so until this day. So I have been through the mill and can look at this thing from all sides. It is a step in the right direction for this Society to say what the conditions should be.

JAMES A. DONNELLY: Look at it from the owner's point of view. Whether he buys a ventilation equipment or not, he likes to have it tested, so that he knows it is turned over in operating condition. Another thing—loans are very often made by insurance companies and others and they will not approve the specifications very often unless there are tests of the mechanical apparatus. In other words, the builder cannot get his loan from the mortgage until the test is made. Irrespective of the heating engineers or whether it is a piping or heating contractor, these different elements call for tests. It may be a difficult situation to meet, but the piping contractors have been trying for 20 years to get it straightened out. Therefore, we may not be able to do it in 2 years, but at least we should try.

THE PRESIDENT: I have been listening to this discussion and I have gotten a great deal out of it. So far I have the names of Messrs. E. E. McNair, L. A. Harding, Charles Lamb, Foster Milliken and R. J. Laurie. It seems to me that some one will have to guarantee the boiler for a certain number of heat units, if the stack is right, and some one will have to guarantee the radiators. I think the architect will have to guarantee, if a certain amount of heat is delivered in the building, that a certain degree of temperature will be maintained.

No. 563

NEW METHODS FOR APPLYING REFRIGERATION

By E. S. H. Baars[1] Milwaukee, Wis.

Non-Member

It is the intention to bring out in this paper not only how refrigeration is applied in new fields, but also changes in the application of refrigeration in industries which have long been employing this useful servant. As this is intended to serve as a review it will be well to follow a guide by which in a general way one may group the different applications of refrigeration as follows:

A. Manufacturing of ice.

B. Cooling of rooms.

- I. Cooling by piping. (a) cooling with evaporating coils
  - (b) cooling with brine piping
- II. Air cooling. (a) dry air coolers (1) evaporating coils
  - (2) brine
  - (b) wet air coolers (1) sprays over evaporating coils
    - (2) brine
    - (3) sprays only
- III. Combined air and direct cooling apparatus.

C. Cooling of liquids and separating of ingredients by congealing.

- I. Pure cooling of liquids. (a) submerged coolers
  - (b) open coolers
  - (c) enclosed coolers
- II. Cooling for separating bodies.
- III. Cooling for congealing.

A. Ice-making apparatus have been, as mentioned before, sufficiently covered in previous years so that there is hardly anything to be added to improve their efficiency or construction. There have hardly been new fields of applications of direct or indirect cooling systems; but there has been quite a change in applying refrigeration for cooling products such as ice cream, chocolate, glue, fish, etc., and changes have taken place from cooling by air with pipes in the

[1] Vilter Manufacturing Co., Milwaukee, Wis.

Paper presented at the Joint Session with The American Society of Refrigerating Engineers at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

room to indirect air cooling, even to immersion in the cooling medium like brine.

It might be well to call attention to a most novel and probably new application of refrigeration which has been installed in connection with a frog farm. At certain seasons of the year frogs are very plentiful and are caught in large quantities and placed in covered concrete trenches. It was noted that as long as the air remained cool the frogs were quiet and most of the time under water. On the other hand a week of hot weather might cause the loss of a large percentage of the stock due to the persistent and continued efforts made to climb out of the trenches into the air. Those that did not die from exhaustion became thin and unfit for the market. Flushing the trenches with large quantities of the coldest water

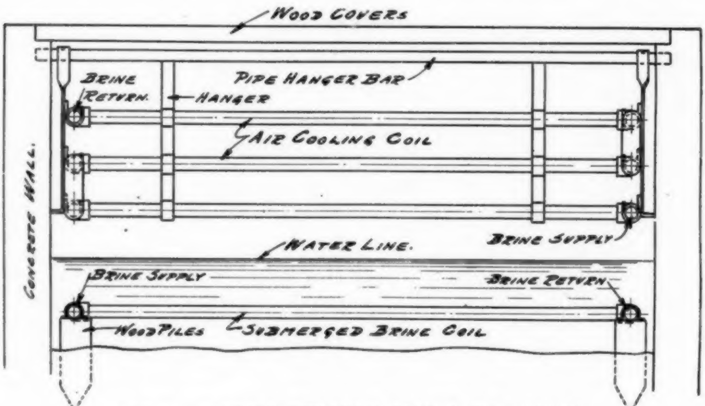

FIG. 1. SECTION THROUGH FROG FARM TRENCH

available did not avoid the losses and finally a refrigerating equipment was installed and a few brine pipes located in the trenches, the air refrigerated, and conditions reproduced in midsummer which naturally prevailed during the cool weather thus avoiding the large losses due to hot weather.

B-I-*a* and B-II-*a*-1. By saying there has been quite a change in applying refrigeration for cooling products I have reference, for instance, to ice cream-hardening rooms which have been mostly cooled by air circulation, and now there seems to be a tendency to install still-hardening rooms.

The amount of cooling surface installed seems to be about the same with either still or air-circulating systems. I know the installations and methods for operating ice cream factories have not been sufficiently standardized to determine the actual saving of one over the other. The determining factors, however, will be the suction pressure carried, the capacity of compressor used, and the power required by the fan which circulates the air. This power ultimately

has to be taken care of in form of heat by the refrigerating machine, and for that reason I mentioned the capacity of the refrigerating machine. This means that the suction pressure required for a still-hardening room is less than that of one with indirect air cooling; the extra energy required to furnish the same amount of refrigeration at lower suction pressure should be compared with the energy required by the fan plus the required energy, producing refrigeration to take care of the heat into which the power put into the moving air, is transformed.

B-II-*a*-1. For cooling chocolate and glue two very similar apparatus have been designed. Both materials are placed on an endless conveyor-belt and the cold air is passed over them in a direction opposite to the movement of the belt. The cooling piping is placed below or alongside of the belt and the apparatus are well insulated. The cooling of chocolate in this manner has been the European practice for years, the arrangement of the apparatus being a trifle

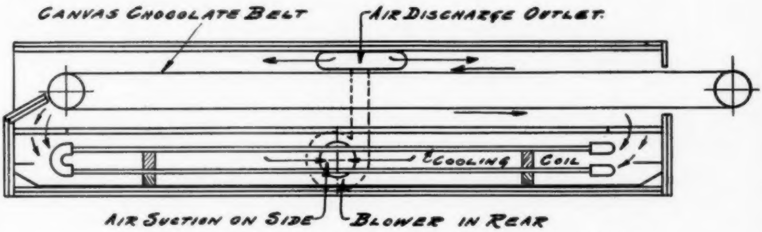

FIG. 2. SECTION THROUGH REFRIGERATED CHOCOLATE COOLER

different; but the principal is the same. In the design of these coolers one has gone a step farther and is cooling the chocolate in moulds, thus saving the refrigeration required for a large room and the heat emitted by the people handling the material. As far as I know the conveyor-belt system is mainly used in chocolate factories for manufacturing small pieces where such pieces can be given a suitable form without a mould.

For cooling glue the conveyor-belt is provided with a rim which prevents the liquid from running off and permits a sufficiently heavy layer to be spread, to leave the dried glue of sufficient thickness for handling. In connection with a glue-cooling arrangement there is a spreading apparatus, for applying the glue to the belt, and a scraping apparatus installed for removing the glue from the belt. The latter removes the glue, after becoming solidified to consistency of gelatine, such as prepared for table use. The cutting of the glue and the spreading of the pieces on wire screens is done at this stage of the process. The old method of cooling glue in large moulds in refrigerated rooms has been supplanted by the above described method.

B-II-*b*-3 In the design of the fan type wet-air coolers there is nothing new to record, but there have been added quite a number of

applications to new industries, such as large bakeries, chewing gum factories, match factories, photographic film manufacture, etc.

One recent construction of wet-air cooler is that which is mainly used in new installations of packing plants and that makes use of the spray nozzle in the lofts above chill rooms. The refrigeration magazines have given comparatively little information about this new system which seems surprising because it appears very promising for it has a number of advantages.

Where with the old-style coil lofts with either the direct evaporating or brine piping the width of the loft has been arranged for 16 ft. bays, the brine-spray system will permit a construction of double the width, because the brine spray will induce sufficient circulation, and a nozzle which throws a full cone spray seems to be the more desirable; besides this it should not require too much pressure. General

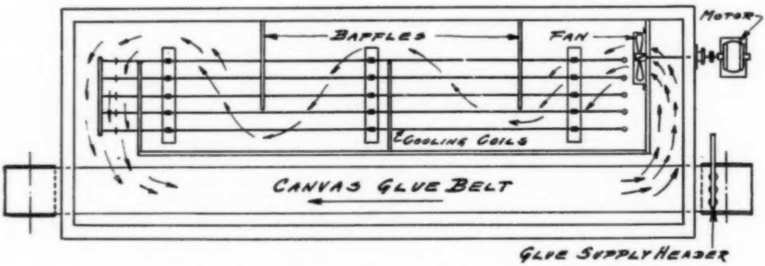

FIG. 3. PLAN OF REFRIGERATED GLUE COOLER

practice seems to place the nozzles having threads for ½ in. pipe connections about 18 in. apart. The lofts have to be waterproofed and well insulated to give satisfactory results.[1]

Comparing a brine-spray system with other systems, the first thing that has to be mentioned is the cheapness of its first cost.

As far as economical operation is concerned not much can be said, because little has been published and probably no tests have been made to gather sufficient information from actual operating conditions; it will, without question, be more economical than a straight brine system with pipes only, because it unquestionably will obtain lower air temperatures than are possible to get with brine piping in the room when using brine of same temperature.

In order to compare the brine-spray system having double-pipe or shell-type brine coolers with an installation having ammonia-evaporating coils, both as usually installed for chilling hogs, it will be permissible to make assumptions as nearly as possible to practical conditions and analyze the results. Assume the air temperature in room 32 deg. fahr.; ammonia-evaporating temperature 12 deg. fahr.,

[1] In the January, 1922, Journal of the AMERICAN SOCIETY OF REFRIGERATING ENGINEERS, S. C. Bloom, in Brine Spray Refrigeration, covers the subject in a most thorough manner and the information given may be applied to similar cases in the art.

corresponding to a suction pressure of 25 lb. and with average length of suction pipe, would probably require a suction pressure of 20 lb. at the compressor. With the use of the spray system it has been found that air temperature can be obtained about 5 deg. fahr. above the temperature of the return brine, so the return brine temperature can be assumed at 27 deg. fahr. which, with a range of 5 deg. would fix the temperature of the brine leaving brine cooler at 22 deg. fahr. A difference between ammonia and brine leaving the cooler of 7 deg. would require an ammonia-evaporating temperature of 15 deg., corresponding pressure 28 lb. As it is generally

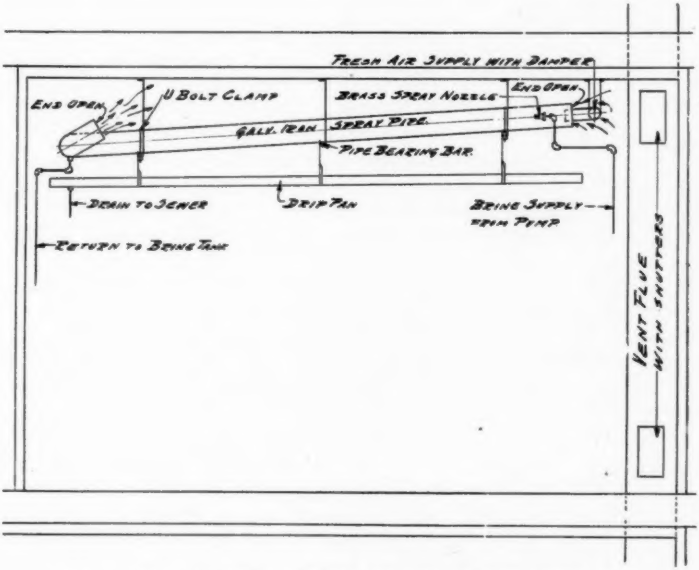

FIG. 4. SECTION THROUGH COOLER WITH BRINE SPRAY PIPE

possible to place the brine-tank cooler and compressor close together a drop of 3 lb. allowed is ample and 25 lb. gauge would in this case be satisfactory. Assuming that 100 tons refrigeration would be required in either case would mean that about 137 h.p. would be required at the compressor in case of the direct piping and about 124 h.p. for operating at the brine cooler; the difference in power would permit operating a 500 gal. per min. capacity centrifugal-brine pump having an efficiency of 65 per cent without using more power than required by the ammonia system. Due consideration should be given to the short ammonia lines and loss of ammonia and as mentioned previously the fixed charges on cost of equipment.

B-III. Combined direct and air-cooling systems are not generally known in this country; however, they are very desirable where it is necessary to add fresh air or remove odors. Brine sprays may be a simple means for adding fresh air to cold storage rooms in which brine piping is used for cooling. A ¾ in. brine spray nozzle in this case could be placed in an 8 in. galvanized pipe, the outlet end of which is turned upward to catch the brine. At the point where the bend starts the brine is drained off. It is advisable to provide a small drip pan for the pipe to catch the moisture which condenses on it. The pipe should be as long as possible to allow proper separation of the brine from the air. The air is induced and cooled by the spray, circulated and at the same time enough suction is created to draw in a supply of fresh air.

C. During the war quite a number of cooling plants for cooling oil or other liquids for chilling purposes have been installed but such installations in general were not different from those used for making plowshares and other agricultural implements.

C-I-*a*. To cool chemicals which attack iron, lead coils can be used which are held in place by wooden straps in a wooden vat. Superior to this, if the chemical can be pumped through the coil, is the arrangement of an atmospheric type of cooler over which cold brine is sprayed.

C-I-*b*. In case of a small unit one may arrange an atmospheric expansion coil above the cooling coil through which the chemical is pumped. Brine is circulated first over the ammonia coil and cooled on its way over. On the next coil it takes up heat from the chemical and finally the brine collects in a pan or tank which is located below the coil and recirculates through the cycle described before.

C-II. Refrigeration is also employed to aid crystallization and for this a unique design has been perfected. The solution to be treated is put in a round tank with a conical bottom which terminates in a valve similar to a molasses cock. A helical cooling coil is placed in this tank and a vertical agitator which has vertical pedals to which brushes are fastened to brush off the crystals which form on the cooling coil. The crystals accumulate in the conical part of the tank and are drawn off from time to time through the valve mentioned before.

C-III. With reference to cooling for congealing I wish to remark that hardly any changes have been made in the design of apparatus except that the two-stage or low-temperature compressor has invaded the field formerly dominated by the absorption machines.

Conclusion. I hope that this review has brought forward something new and of interest to everyone and that each one may be able to add to this out of his experience to complete and round out what has been touched upon using the schedule given at the beginning.

No. 564

THEORY OF HEAT LOSSES FROM PIPES BURIED IN THE GROUND

By John R. Allen, Pittsburgh, Pa.

Member

VERY little information is available in engineering literature regarding the theory of heat losses from pipes buried in the ground, and it is very difficult to find any discussion of the physical laws governing such losses of heat. In this paper it is the intention to discuss the laws governing these losses and to apply them in a general way to ordinary practice. The results given are not absolute and must be considered as relative; it is not possible at the present time to give results of absolute values, owing to the fact that very little experimental data are available on this subject. What data the author has been able to obtain have tended to prove that the theories advanced in this article are substantially correct. From the results developed in this article the following conclusions may be drawn:

1 (*A*) That the heat loss from a pipe is not proportional to the external surface of the pipe. The heat loss per square foot of pipe in small pipes is very much larger than the heat loss per square foot in large pipes.

2. (*A*) That the heat loss from a pipe is not inversely proportional to the thickness of the covering and the larger the pipe the thicker the covering that can be economically used.

3. (*A*) That the depth to which a covered pipe is buried in the soil makes very little difference in the heat loss, provided the center of the pipe is 2 ft. or more below the ground surface. Beyond 2 ft. in depth, unless the pipes are very large, the heat loss from the pipes remains substantially the same for all depths.

4. (*A*) That the heat loss from a pipe is not proportional to the conductivity of the covering, as the conductivity of the ground is as important a factor in the heat losses as the conductivity of the covering.

Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis Mo., May, 1920.

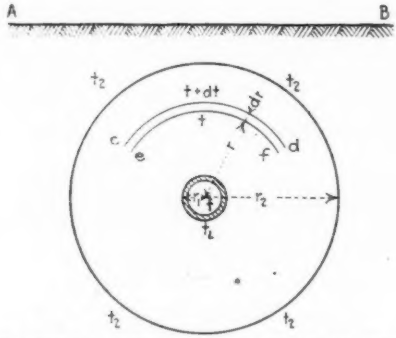

FIG. 1. BARE STEAM PIPE BURIED DEEPLY IN THE GROUND.

4. (*B*) That poor covering in dry ground will give better results than good covering in wet ground. It is not possible, therefore, to guarantee the heat loss from a covering in the ground, as such a guarantee involves guaranteeing the conductivity of the ground.

THEORY OF HEAT LOSS

The discussion that follows may be criticised because it involves certain assumptions. These assumptions have been made in order to reduce the equations to a simpler form and do not seriously affect the results as far as can be determined. In any case, there are so many factors entering into the problem that a complete rigid mathematical treatment is not possible except for the case of a pipe buried very deeply in the ground. It appears from the results that such a rigid mathematical treatment is not necessary, as the difference in the heat loss between pipes reasonably close to the surface and those buried very deeply in the ground is not very great.

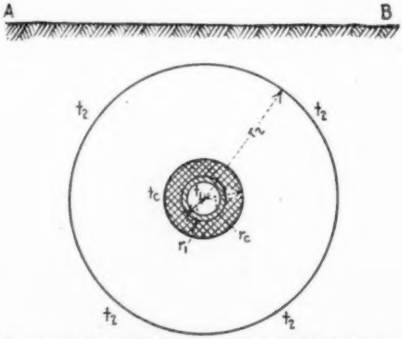

FIG. 2. COVERED STEAM PIPE BURIED DEEPLY IN THE GROUND.

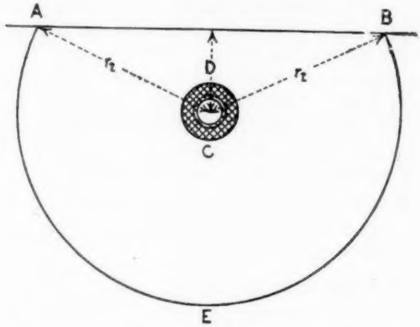

FIG. 3. COVERED STEAM PIPE BURIED IN THE GROUND CLOSE TO THE SURFACE.

There is a fundamental difference between the heat loss from a pipe in the ground and a pipe in the air. With a pipe in the air either bare or covered, the final loss to the surrounding air and objects occurs by conduction and convection. With a pipe buried in the ground either bare or covered, the final heat loss is by conduction through the earth envelope surrounding the pipe. It is not possible, therefore, to apply the constants and equations to pipes buried in the ground which have been found for pipes exposed in the air, as the processes of heat transmission are entirely different and covered by entirely different physical laws.

In the development of the expressions for the heat losses from pipes buried in the ground there are three distinct cases which have been taken into consideration:

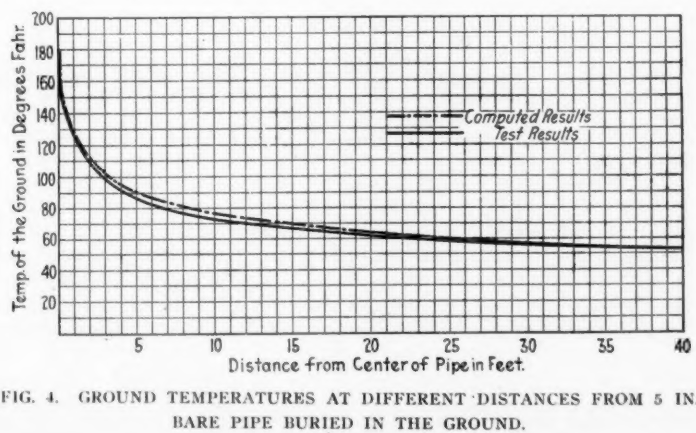

FIG. 4. GROUND TEMPERATURES AT DIFFERENT DISTANCES FROM 5 IN. BARE PIPE BURIED IN THE GROUND.

1. Where the pipe is bare and buried so deeply in the ground that its temperature does not materially affect the temperature of the surface of the ground in contact with the air.
2. Where the pipe is covered and buried so deeply in the ground that its temperature does not materially affect the temperature of the surface of the ground in contact with the air.
3. Where the pipe is covered and close enough to the surface so that its temperature does affect the surface of the ground in contact with the air.

The theory of each one of these different cases will be taken up and discussed separately.

Case 1. *Bare Pipe Buried Deeply.* The mathematical expression for the heat loss from a pipe buried deeply in the ground may be obtained by a consideration of Fig. 1. Let AB be the ground surface, the pipe being buried in the ground at a depth great enough so that its temperature does not materially affect the temperature of the ground surface. Let r_2 be the distance from the pipe at which the ground has a practically uniform temperature of t_2. Let the radius of the pipe be r_1 and its temperature t_1. The isothermal lines, that is, the lines of constant temperature, are now concentric circles, provided the ground is homogeneous. Take two concentric circles, *cd* and *ef*, separated from each other by a distance *dr*. The difference of temperature between these two isothermals will be *dt*. If the temperature of the circle *ef* is *t*, then the temperature of the circle *cd* will be $t + dt$. From physical laws, we know that heat conduction varies as the difference of temperature, as the conductivity of the material *k*, inversely as the distance through which the heat is conducted, also directly as the area through which the heat is transmitted. With these laws in mind, we can therefore write the heat transmission from the circle *ef* to the circle *cd* which will be expressed by the following equation:

$$H=\frac{akdt}{dr} \quad \text{But } a = 2\Pi r \quad \text{Hence}$$

$$H=\frac{2\Pi rkdt}{dr}=\frac{\frac{2\Pi kdt}{dr}}{r}$$

Integrating t between the limits t_1 and t_2, and r between the limits r_2 and r_1 we have:

$$H=\frac{2\,\Pi\,k\displaystyle\int_{t_2}^{t_1} dt}{\displaystyle\int_{r_1}^{r_2}\frac{dr}{r}}=\frac{2\Pi k(t_1-t_2)}{\log\frac{r_2}{r_1}} \qquad (1)$$

where

$H =$ the heat loss in B.t.u. per hour per linear foot of pipe.

t_1 = the temperature of the outside of the pipe, usually assumed as the temperature of the steam or water in the pipe in degrees fahrenheit.

t_2 = the average temperature of the ground at a point where the heat of the pipe does not affect its temperature appreciably, degrees fahrenheit.

r_2 = the distance from the center of pipe in feet at which the temperature of the ground becomes t_2.

r_1 = the radius of the pipe in feet.

k = the conductivity of the ground expressed in B.t.u. transmitted per hour per degree difference of temperature fahrenheit per foot of thickness.

The constant k will always be an uncertain factor. For dry soils it is about 0.2 and for wet soils it is about 0.9. As soil is usually wet, the constant 0.9 will be a more nearly average condition than 0.2. The wide variation in the value of the constant k will always give experiments with pipes laid in the ground a wide variation of results. In fact, these experiments will be changed by local conditions. This has been already noted in experiments with which the writer was connected some years ago at the University of Michigan, which show that a rainstorm materially increases the heat loss of the pipe. This, of course, is due to increased conductivity of the ground. In the case where a current of water actually passes through the soil around the pipe, the constant k may have a very much larger value than 0.9.

Equation (1) shows that the heat loss of the pipe depends directly upon the conductivity of the soil, the difference in temperature between the stable ground temperature and the temperature of the pipe, and is inversely as the logarithm of the ratio of the distances r_2 and r_1. As all the distances are involved as logarithms, it is at once apparent that distances will have far less effect than the other factors. This is apparent when we consider that the logarithm of 100 is 2 and the logarithm of 10 is 1, so that increasing the distances ten times only doubles the logarithmic values.

Case II. Covered Pipe Buried Deeply. In the case of a covered pipe buried deeply in the ground, there are two different materials through which the heat is conducted. The amount of heat passing through the covering and through the ground however, will be the same. By exactly the same mathematical processes by which equation (1) has been derived, we can derive a separate expression for the heat loss through the covering and the heat loss through the ground. The heat loss through the ground H_1 will be:

$$H_1 = \frac{2\Pi k(t_c - t_2)}{\log \frac{r_2}{r_c}} \qquad (2)$$

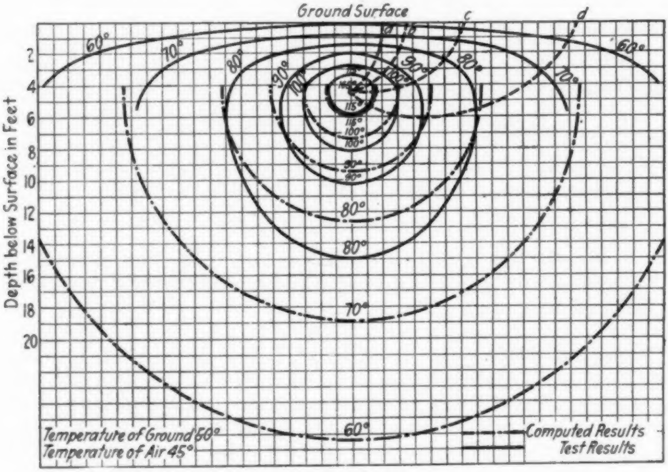

FIG. 5. ISOTHERMAL LINES SURROUNDING THE PIPE.

where H_1, t_1, t_2, r_1, r_2, and k represent the same quantities as in equation (1).

and t_c = the temperature of the outer surface of covering in degrees fahrenheit.

r_c = the radius of the covering in feet.

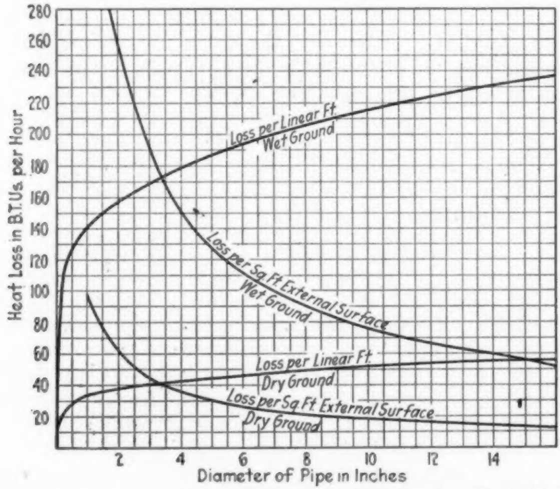

FIG. 6. EFFECT OF PIPE SIZE ON THE HEAT LOSS FROM BARE PIPE BURIED DEEPLY IN THE GROUND.

And in the same way the heat loss through the covering H_2 will be:

$$H_1 = H_2 = \frac{2\Pi k_c\,(t_1 - t_c)}{\log \frac{r_c}{r_1}} \qquad (3)$$

where

k_c = the conductivity of the covering expressed in B.t.u. transmitted per hour per degree difference of temperature fahrenheit per foot of thickness.

The temperature t_c (Fig. 2) is an unknown quantity but it may be eliminated by finding the value of t_c from both equations (2) and (3). Equating these two values and solving for H_1 the result obtained is as follows:

$$H_1 = \frac{2\Pi k\,k_c\,(t_1 - t_2)}{k_c \log \frac{r_2}{r_c} + k \log \frac{r_c}{r_1}} \qquad (4)$$

Equation (4) shows that, with pipe buried in the ground, both the conductivity of the ground and the conductivity of the covering enter into the heat loss. They do not enter, however, as simple quantities so the heat loss will not vary directly as the conductivity of the ground nor directly as the conductivity of the covering but as the product of the two conductivities. As in the case of equation (1) all the distances are involved as logarithmic functions and therefore small differences of distance will make very little difference in results.

Case III. Covered Pipe Close to the Ground. In the actual installation of distributing systems in the ground, it is seldom that the distance from the surface of the ground to the center of the pipe exceeds 10 ft. In considering this case, it is assumed that all of the heat leaving the pipe toward the ground side passes through segment AEB, Fig. 3, and that all the heat going immediately to the ground surface passes through the sector ACB.

In Fig. 3, the relative proportion of D and r_2 is not to scale. In actual practice r_2 would be from eight to ten times the value of D, so that the angle ABC would be very small, usually less than 5 deg. and ACB would then be practically a straight line. Since the angle ACB is very close to 180 deg. it can be assumed as such without involving any very appreciable error. All of the heat given off from the lower half of the pipe has been considered as going to the ground, and all of the heat given off from the upper

half of the pipe as going directly to the surface of the ground[1]. The total heat loss, therefore, in this case will be the sum of the heat lost to the surface of the ground and the heat lost to the ground itself.

Then $$H = H_1 + H_2$$

where H_1 = Heat lost to the ground.

H_2 = Heat lost toward the surface of the earth.

H_1 can now be determined directly from equation (4) and it will be exactly one half of the value of equation (4). Hence:

$$H_1 = \frac{\Pi k\, k_c\, (t_1 - t_2)}{k_c \log \frac{r_2}{r_c} + k \log \frac{r_c}{r_1}} \qquad (5)$$

The heat lost from the upper half of the pipe to the ground surface may be represented by an equation of the same general form as equation (5). The only difference will be that the distance traversed by the heat will now be shorter than in the case where the pipes are buried deeply in the ground. The temperature t_2 will now become the average temperature of the ground surface t_g. The distance to the ground surface where the temperature is t_g will now become approximately the average distance from the pipe to the ground within the radius r_2 for the upper surface. This distance may be approximately represented by $\frac{r_2 + D}{2}$. It is now possible to write an equation similar to equation (4) by analogy. This equation will be as follows:

$$H_2 = \frac{\Pi k\, k_c\, (t_1 - t_g)}{k_c \log \frac{r_2 + D}{2\, r_c} + k \log \frac{r_c}{r_1}} \qquad (6)$$

in which

D = the depth from the ground surface to the center of the pipe in feet.

t_g = average temperature of ground for a distance $2r_2$.

All other quantities have the same value as in the previous equations. Adding equation (5) and (6) we have the total heat loss from the pipe per linear foot:

$$H = H_1 + H_2 = \frac{\Pi k\, k_c\, (t_1 - t_2)}{k_c \log \frac{r_2}{r_c} + k \log \frac{r_c}{r_1}} + \frac{\Pi k\, k_c\, (t_1 - t_g)}{k_c \log \frac{r_2 + D}{2\, r_c} + k \log \frac{r_c}{r_1}} \qquad (7)$$

DISTRIBUTION OF TEMPERATURES IN THE GROUND

In Case I and Case II, where the pipes are buried deeply in the ground, it seems reasonable to assume that the lines of constant

[1] Finally, of course, all the heat, no matter where it goes initially, gets to the ground surface.

temperature—that is, the isothermal lines surrounding the pipe—are circles. In this case the temperature of the isothermals for any distance from the pipe may be determined from equation (1) or from equation (4). In the case of the bare pipe buried deeply in the ground (Case I), we can, from analogy with equation (1), write the value of the heat transfer for any circle distant r feet from the center of the pipe. The expression would be as follows:

$$H_1 = \frac{2\Pi\, k\,(t_1 - t)}{\log \frac{r}{r_1}}$$

where

t = temperature for the isothermal, distant r from the center of the pipe.

This heat transmission must also be equal to the total heat transmission. We know that H_1 must equal the heat passing as given in equation (1) for H.

$$H = \frac{2\Pi\, k\,(t_1 - t_2)}{\log \frac{r_2}{r_1}}$$

Since $H = H_1$, these two equations may be placed equal to each other and the equation solved for the value of t. The solution of these equations gives the following value for t:

$$t = \frac{t_1 \log \frac{r_2}{r} + t_2 \log \frac{r}{r_1}}{\log \frac{r_2}{r_1}} \tag{8}$$

By the same mathematical process we can obtain from equation (5) the expression for the temperature t at any point distant r feet from the center of the pipe for a covered pipe.

$$t = t_1 - \frac{\left(k_c \log \frac{r}{r_c} + k \log \frac{r_c}{r_1}\right)(t_1 - t_2)}{k_c \log \frac{r_2}{r_c} + k \log \frac{r_c}{r_1}} \tag{9}$$

The meaning of these equations may be best seen by plotting the temperature at different distances from the pipe.

Fig. 4 shows the ground temperature, at different distances, of a bare pipe buried in the ground. The computed results shown in the curve are plotted for the following assumptions:

$t_2 = 165$
$t_1 = 50$
$r_2 = 40$
$r_1 = \frac{1}{8}$ (3 in. pipe)

These quantities were substituted in equation (8) and the computed results are shown in a dot and dash line in the figure; the test results are shown in a solid line. It will be noticed that the test results and the computed results are very close to each other, which would seem to show that the theory is reasonably correct in its application.

The computed curve shown in Fig. 4 is for pipe buried deeply in the ground, while the test curve is for pipe about 5 ft., 6 in. in the ground. This accounts for the apparent difference in the

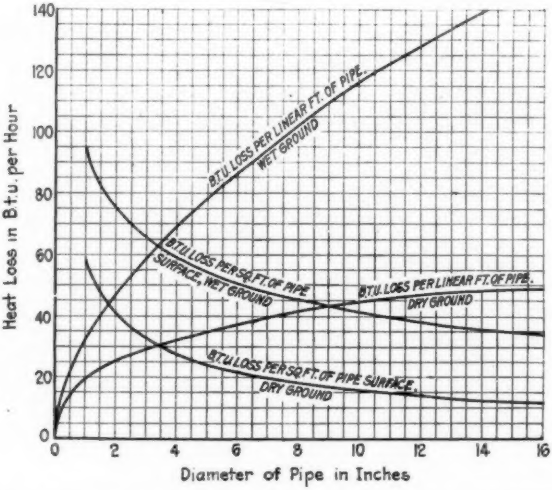

FIG. 7. CURVES SHOWING EFFECT OF PIPE SIZE ON HEAT LOSS FROM COVERED PIPE BURIED DEEPLY IN THE GROUND.

results. The fact that these two curves are very close together goes to prove an assumption that will be made later, that the effect of the ground surface is not a very large factor in the heat loss from a pipe. This same fact can be seen from Fig. 5.

Fig. 5 shows the isothermal lines surrounding the pipe. The solid lines are taken from actual experiment. The dot and dash lines are obtained by computation. In the experiments, the actual temperatures were not obtained below 90 deg. In this illustration, the pipe is assumed to be at a temperature of 165 deg. and was buried 4 ft., 6 in. below the surface. It will be noticed that the isothermals close to the pipe, that is, from 165 deg. down to the isothermals 115 deg. were hardly changed in their circular form but as the lower isothermals come close to the surface, they are depressed by the temper-

ature of the ground surface and finally become circles of infinite radius or straight lines parallel to the ground surface.

The heat flow is always at right angles to the isothermal lines or radial curves. The dotted lines a and b, etc., represent approximately the lines of flow of heat. It will be noted that, even when the pipe is quite close to the surface, these lines of heat flow have a fairly long path for even the upper surfaces of the pipe. The effect of the ground temperature is to flatten the circles on the sides slightly, due to the fact that the heat loss to the ground surface is more rapid than to the ground itself.

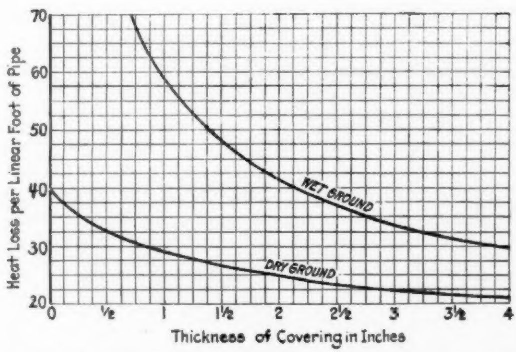

FIG. 8. CURVES SHOWING EFFECT OF DIFFERENT THICKNESSES OF COVERING ON HEAT LOSS FROM 3 IN. PIPE BURIED DEEPLY IN THE GROUND.

The temperature of the ground drops very rapidly close to the surface of the ground so that the actual temperature of the ground surface for any considerable distance either way from the pipe center line is only slightly above the temperature of the air. Experiments show that the difference in the average ground temperature for distances 20 ft. either side of the pipe, and the air temperature of the surrounding air, is usually not more than 1 deg. Directly above the center of the pipe, the temperature of the ground surface will be appreciably warmer but this higher temperature drops very rapidly either side of the center line of the pipe. For practical considerations, the temperature of the ground surface can be taken as the temperature of the outside air above the ground without introducing any very appreciable error.

EFFECT OF SIZE OF PIPE

In the expression for the heat loss from a bare pipe buried in the ground, equation (1), the radius of the pipe r_1 is involved as

a logarithmic function in the denominator. Therefore slight changes in the dimensions will have small effect upon the final results. This will be seen by a study of the curves shown in Fig. 6. In computing the curves in Fig. 6 the following assumptions have been made:

$t_1 = 225 \quad t_2 = 50 \quad r_2 = 40 \quad r_1 = \text{variable} \quad \text{Value of } k = 0.89$

The most doubtful factor is the value of k which varies with all soil and may have a value in excess of 1.2 as shown by some recent

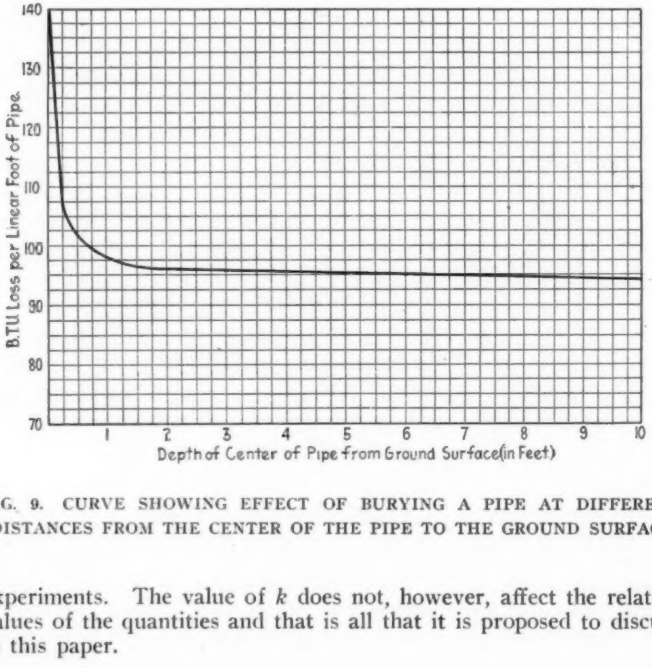

FIG. 9. CURVE SHOWING EFFECT OF BURYING A PIPE AT DIFFERENT DISTANCES FROM THE CENTER OF THE PIPE TO THE GROUND SURFACE

experiments. The value of k does not, however, affect the relative values of the quantities and that is all that it is proposed to discuss in this paper.

It will be noticed in Fig. 6 that, in moist soil for pipe sizes above 6 in., increased size of pipe does not increase the heat loss rapidly and the heat loss is not proportional to square feet of pipe surface as shown in the curve, but drops very rapidly as the pipes increase in size. The curve shows that a linear foot of 12-in. pipe only loses 15 per cent more heat than a linear foot of 6-in. pipe. In sizes below two inches the effect is very marked as the heat loss then drops very rapidly with the size of the pipe.

Fig. 7 shows similar curves for a pipe covered with 1 in. thickness of infusorial earth buried deeply in the ground. In computing

curves for Fig. 7, the following quantities have been substituted in equation (4).

$$t_1 = 225 \qquad t_2 = 50 \qquad r_2 = 40 \qquad r_1 = \text{variable}$$

$$r_c = r_1 + 1 \text{ in. of covering} \qquad k_c = 0.04$$

A comparison of Fig. 6 and Fig. 7 shows that the effect of the covering is to materially reduce the heat loss in wet soils. With a good covering, wet soil increases heat loss approximately 150 per cent, while with a bare pipe, wet soil increases heat loss as compared with dry soil to 450 per cent. The curves for covered pipe have the same general form as the curves for bare pipe. Above 4

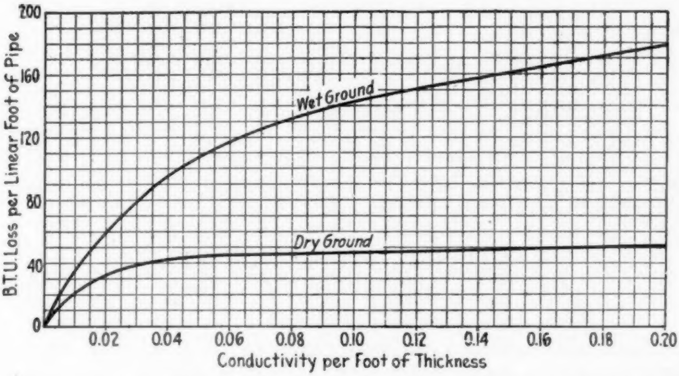

FIG. 10. CURVES SHOWING EFFECT OF COVERINGS HAVING DIFFERENT CONDUCTIVITIES, ON THE HEAT LOSSES FROM THE PIPE.

in. the heat loss per linear foot does not increase as rapidly as the size of pipe increases.

The curves for covered pipe have the same general form as the curves for bare pipe. Above 6 in. the heat loss per linear foot does not increase as rapidly as the size of pipe increases. A 16 in. pipe, covered, in a wet soil, loses only 8 per cent more heat per linear foot than a 10 in. pipe.

The effect of pipe size on covered pipe near the surface has not been taken up in a separate curve as the diagram is almost the same as for the pipes buried deeply in the ground.

EFFECT OF DIFFERENT THICKNESSES OF COVERING

An important question is the relative effect of different thicknesses of covering on the heat loss from the pipe per linear foot. Fig. 8 shows the heat losses for various thicknesses of covering for a

pipe buried deeply in the ground. The quantities in Fig. 8 have been computed in equation (4) with the following assumptions:

$t_1 = 225 \quad t_2 = 50 \quad r_2 = 40 \quad r_1 = \frac{1}{8}$ ft. (3 in. pipe) $\quad r_c =$ variable
$k = 0.89$ for wet earth and 0.212 for dry earth $\quad k_c = 0.04$

The curves show that for wet ground the heat loss reduces very rapidly as the thickness of the covering increases up to 2 in., and from 2 in. up the increase is quite gradual. For dry ground, the effect of increasing the thickness of covering is much more gradual, and above 1½ in. becomes almost nothing. As most installations are made in ground which is wet, the wet ground curve should be the criterion in considering this question. This curve shows then that for wet ground there is very little advantage in increasing the thickness of the pipe covering with a good grade of covering to more than 2 in.

PIPES NEAR THE SURFACE

The expression for the heat loss in the case of a pipe near the surface is given in equation (7). This equation includes the quantity t_s which is unknown, but as has been shown in a previous paragraph t_s may be taken as the air temperature t_a. Substituting this temperature for t_s in equation (7) we have:

$$H = \frac{\Pi\, k\, k_c\, (t_1 - t_2)}{k_c \log \frac{r_2}{r_c} + k \log \frac{r_{c'}}{r_1}} + \frac{\Pi\, k\, k_c\, (t_1 - t_a)}{k_c \log \frac{r_2 + D}{2\, r_c} + k \log \frac{r_c}{r_1}} \qquad (10)$$

From this equation we may determine the relative effect of burying pipe in the ground at different depths from the center of the pipe to the surface of the earth. In constructing Fig. 9, the following assumptions have been made:

$t_2 = 225 \quad t_1 = 50 \quad t_a = 35 \quad r_{2'} = 40 \quad r_1 = \frac{1}{4}$ ft. (6 in. pipe)
$k_c = 0.04 \quad k = 0.9 \quad D =$ variable $\quad r_c = r_1 + 1$ in. covering.

Fig. 9 shows that where a pipe is covered with a depth of earth of more than 2 ft., increasing the depth of the pipe in the ground has very little effect upon the heat loss per linear foot. The reason for this is that the lines of heat flow are always at right angles to the isothermal lines and, therefore, even when the pipe is quite close to the surface, most of the heat has to take a relatively long path through the earth. This is shown in the dotted lines of heat flow in Fig. 5. It seems therefore, that there is no particular object in burying a pipe deeper in the ground than is necessary to prevent its being disturbed by outside causes.

COVERINGS WITH DIFFERENT CONDUCTIVITIES

Equation (10) shows that the conductivity of the pipe covering enters both in the denominator and in the numerator of the frac-

tion and not as a simple quantity, so that the only means of determining the effect of changing the conductivity will be by means of a curve.

Fig. 10 shows graphically the effect of using coverings having different conductivities for both wet and dry soil. In drawing these curves, the following assumptions have been made:

$t_2 = 225$ $t_1 = 50$ $r_2 = 40$ ft. $r_1 = 1/4$ ft. (6 in. pipe) $r_c = 1/3$ ft.
$D = 4$ ft. $k = 0.9$ wet soil and 0.212 dry soil. $k_c =$ variable.

The curve for wet soil rises rapidly up to a conductivity of 0.06 and beyond that point becomes almost a straight line. For conductivities below 0.06 the effect of reducing the conductivity is much more marked than for conductivities above 0.06. As an example, changing the conductivity of the covering from 0.1 to 0.2, that is, doubling it, only increases the heat loss 25 per cent. In dry ground the effect is still more noticeable and increasing the conductivity from 0.1 to 0.2 increases the heat loss only 10 per cent. All the better grades of covering have conductivities less than 0.08 and the very best goes as low as 0.03. In this range of conductivities, the effect of conductivity is much more marked, and increasing the conductivity from 0.03 to 0.06 increases the heat loss for wet ground 50 per cent. It will also be noticed by comparing curves for wet and dry ground that a poor covering in dry ground will give better results than a good covering in wet ground. For example, a covering having a conductivity of 0.03 in wet ground shows a heat loss of 80 B.t.u. per foot, while a poor covering having a conductivity of 0.1 when placed in dry ground has a heat loss of 48 B.t.u. per foot. The conductivity of the ground therefore plays a very important part in heat losses from pipes either bare or covered that are buried in the ground.

It is not possible according to the foregoing facts for a manufacturer of pipe coverings to guarantee the loss of heat from the covering when it is placed in the ground, as the heat loss from this covering depends very largely upon the condition and kind of ground in which the pipe covering is placed. Asking a manufacturer to guarantee the heat loss from a covering in the ground is fairly asking him to guarantee the conductivity of the soil. The conductivity of different soils has not been extensively studied by the engineer, and presents a field of research worthy of investigation which at the present time is touched only by the astronomer and geologist.

In order to go further into this question of pipe covering losses it will be necessary to make a much more careful study of ground conductivities and ground losses from actual experiment with pipes buried in the ground. Experiments of this kind are now being carried on at the University of Michigan in cooperation with the Research Laboratory. The experiments on bare pipe were commenced about three years ago and are now well under way. When these are finished, experiments will be conducted on covered pipes.

EFFECT OF SIZE OF PIPE ON THICKNESS OF COVERING

As a result of questions that have been raised as to effect of the size of pipe on the thickness of covering, as to losses from multiple coverings, the best arrangement of multiple coverings, and the effect of air spaces, the author desires to present the following summary of the conclusions derived from this analysis:

First.—As the diameter of the pipe increases the desirable thickness of covering used should be increased. With small pipes, 1 in. thickness will ordinarily be all that would be economical; but with larger pipe it may be economical, depending on commercial conditions, to increase the thickness to 2 in. and over.

Second.—In multiple covering, the better covering should be placed next to the pipe and the poorer covering outside in order to insure the minimum heat transmission.

Fig. 11 shows the heat losses per linear foot of a pipe for various sizes of pipes covered with different thicknesses of a covering having a conductivity per foot of 0.04 B.t.u. The curve for 1 in. pipe begins to turn sharply at 1 in. thickness which shows that added thickness above 1 in. will reduce heat transmission only slightly. As the pipes increase in size the sharp bend in the curve moves to the right so that the larger the pipe the greater the desirable thickness. As the pipe becomes larger, the curve becomes flatter and when the radius becomes infinite, that is, when we have a flat surface, the insulating effect would be proportional to the thickness of the covering.

EFFECT OF MULTIPLE COVERINGS

Assume the same conditions as given in Case II, where the pipe is buried in the ground to such a depth that the isothermal lines may be assumed as circles, but, instead of one covering, it has two coverings as shown in Fig. 12, the inner covering having a radius r_c, and the outer covering a radius r_b. Let the quantities used in the following equations have the following significance:

H = Total heat loss from the pipe in B.t.u. per linear ft. per hr.;
t_1 = Temperature of the pipe in deg. fahr.;
t_2 = Temperature of the ground at a point where the temperature becomes substantially constant;
t_c = Temperature of the outside of the inner covering;
t_b = Temperature of the outside of the outer covering;
r_1 = Radius of the pipe in feet;
r_2 = Radius of the isothermal where the ground temperature is substantially constant;

r_c = Radius to the outside of the inner covering;
r_b = Radius to the outside of the outer covering;
k = Conductivity of the ground in B.t.u. per sq. ft. per degree difference fahr. per foot of thickness;
k_c = Conductivity of the inner covering in B.t.u. per sq. ft. per degree difference fahr. per foot of thickness;
k_b = Conductivity of the outer covering in B.t.u. per sq. ft. per degree difference fahr. per foot of thickness;

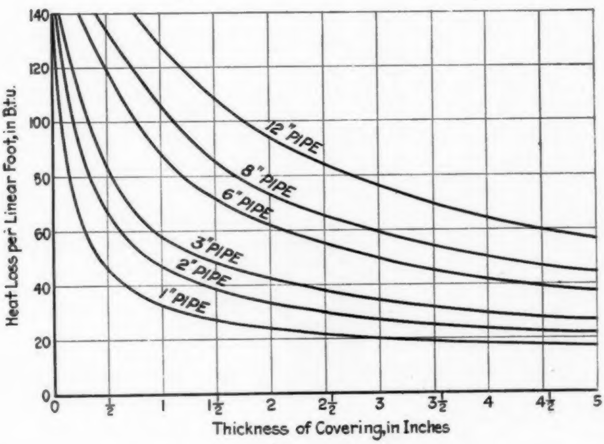

FIG. 11. EFFECT OF PIPE SIZE ON THICKNESS OF COVERING.

$$\text{Then } H_1 = \frac{2\Pi\, k_c\ (t_1 - t_c)}{\log \dfrac{r_c}{r_1}} \tag{11}$$

In the same way the heat lost through the outer covering would be:

$$H_2 = \frac{2\Pi\, k_b\ (t_c - t_b)}{\log \dfrac{r_b}{r_c}} \tag{12}$$

In the same way the heat lost through the ground may be expressed as:

$$H = \frac{2\Pi\, k\ (t_b - t_2)}{\log \dfrac{r_2}{r_b}} \tag{13}$$

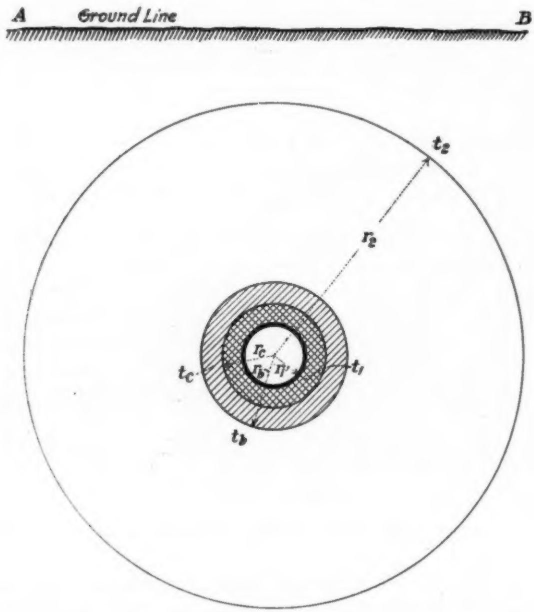

FIG. 12. STEAM PIPE WITH TWO COVERINGS BURIED DEEPLY IN THE GROUND.

But the heat passing out through any isothermal circle must be the same. Therefore:

$$H = H_1 = H_2 = \frac{2\Pi k_c\ (t_1 - t_c)}{\log \dfrac{r_c}{r_1}} = \frac{2\Pi k_b\ (t_c - t_b)}{\log \dfrac{r_b}{r_c}} = \frac{2\Pi k\ (t_b - t_2)}{\log \dfrac{r_2}{r_b}} \tag{14}$$

Solving the first two equations for the t_c and equating them we have:

$$2\Pi k_c k_b t_b = -k_c H \log\frac{r_b}{r_c} + 2\Pi k_c k_b t_1 - k_b H \log\frac{r_c}{r_1}$$

And solving the above equation for t_b:

$$t_b = \frac{-k_c H \log\frac{r_b}{r_c} + 2\Pi k_c k_b t_1 - k_b \mathrm{H} \log\frac{r_c}{r_1}}{2\Pi k_c k_b}$$

Solving the last member of equation (14) for t_b:

$$t_b = \frac{H \log\frac{r_2}{r_b} + 2\Pi k\, t_2}{2\Pi k}$$

Equating the two values of t_b and solving for H:

$$-H\, k\, k_c \log\frac{r_b}{r_c} - H\, k\, k_b \log\frac{r_c}{r_1} - H\, k_c k_b \log\frac{r_2}{r_b} = 2\Pi k\, k_c\, k_b\, (t_2 - t_1)$$

Hence:

$$H = \frac{2\Pi\, k\, k_c k_b\, (t_1 - t_2)}{k\, k_c \log\frac{r_b}{r_c} + k\, k_b \log\frac{r_c}{r_1} + k_c\, k_b \log\frac{r_2}{r_b}}$$

for compound covering of two layers

The equation for one covering is given in equation (4) as follows:

$$H = \frac{2\Pi k\, k_c\, (t_1 - t_2)}{k_c \log\frac{r_2}{r_c} + k \log\frac{r_c}{r_1}} \qquad (16)$$

These two equations are of exactly the same form. We can therefore write by inspection the equation for a covering having any number of layers. Suppose for example, a covering having three layers, c, b, a, with conductivities of k_c, k_b, k_a and with radii of r_c, r_b and r_a respectively; then the equation for this covering can be written as follows:

$$H = \frac{2\Pi k\, k_c k_b k_a\, (t_1 - t_2)}{k\, k_c k_b \log\frac{r_a}{r_b} + k\, k_c k_a \log\frac{r_b}{r_c} + k\, k_a\, k_b \log\frac{r_c}{r_1} + k_a k_b k_c \log\frac{r_2}{r_a}} \qquad (17)$$

These expressions may be easily reduced to the loss per square foot of pipe surface by dividing the expression for H by $2\Pi r$. Performing this operation, equation (16) for one layer of covering becomes:

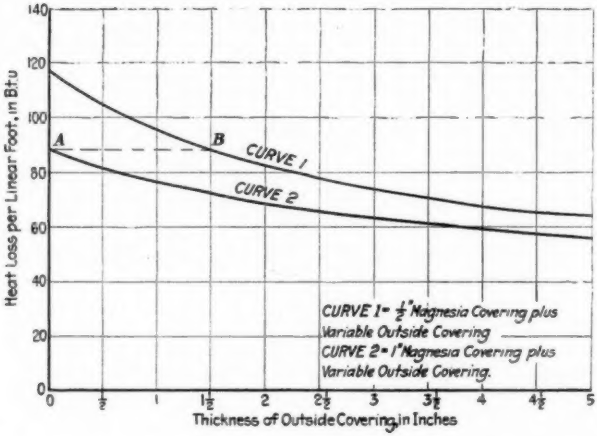

FIG. 13. EFFECT OF MULTIPLE COVERING.

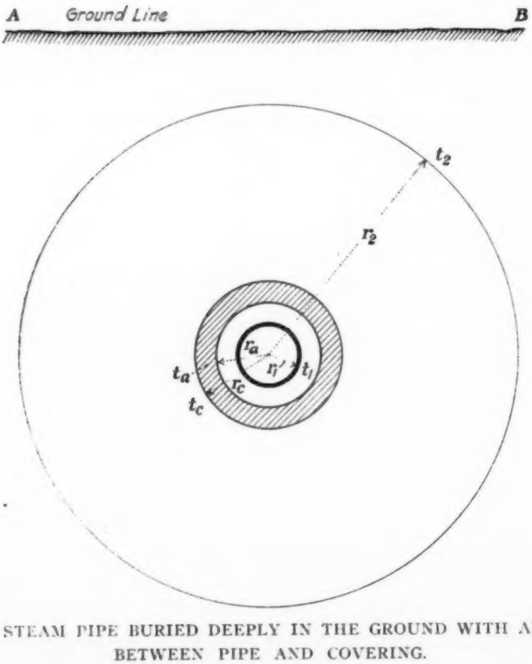

FIG. 14. STEAM PIPE BURIED DEEPLY IN THE GROUND WITH AIR SPACE BETWEEN PIPE AND COVERING.

$$\frac{H}{2\Pi r_1} = \frac{2\Pi k\, k_c\, (t_1 - t_2)}{2\Pi r_1 \left(k_c \log \frac{r_2}{r_c} + k \log \frac{r_c}{r_1}\right)} \text{ or}$$

Loss per square foot of pipe surface, $U = \dfrac{t_1 - t_2}{\dfrac{r_1 \log \frac{r_2}{r_c}}{k} + \dfrac{r_1 \log \frac{r_c}{r_1}}{k_c}}$

In the same way equation (15), for two layers reduces to the following:

$$U = \frac{t_1 - t_2}{\dfrac{r_1 \log \frac{r_b}{r_c}}{k_b} + \dfrac{r_1 \log \frac{r_c}{r_1}}{k_c} + \dfrac{r \log \frac{r_2}{r_b}}{k}}$$

From equation (17) for three layers:

$$U = \frac{t_1 - t_2}{\dfrac{r_1 \log \frac{r_a}{r_b}}{k_a} + \dfrac{r_1 \log \frac{r_c}{r_1}}{k_c} + \dfrac{r_1 \log \frac{r_b}{r_c}}{k_b} + \dfrac{r_1 \log \frac{r_2}{r_a}}{k}}$$

Comparing these expressions it is at once apparent that the expression for any number of coverings can be written by adding the proper terms to the denominator.

ARRANGEMENT OF COVERINGS

A question which naturally arises is in regard to arrangement of the layers of the covering in multiple. Should the better covering be nearest the pipe or away from the pipe? This can be answered by substituting numerical values in equation (15).

Take the case of a covering composed of two different insulating materials, one much better than the other. Assign the following values to the different quantities:

$t_1 = 225$; $t_2 = 50$ deg.; $r_1 = 3/12$ ft.; $r_2 = 40$ ft.; $k = 0.9$

Covering A has a conductivity of 0.04 per foot thickness;
Covering B has a conductivity of 0.1 per foot thickness.

The following table has been worked out for different thicknesses of covering, with good covering next to the pipe and poorer covering outside, and with these conditions reversed.

TABLE 1. HEAT LOSSES WITH DIFFERENT ARRANGEMENTS OF COVERING

	Heat Loss, B.t.u. per foot of length
1 in. of covering A	88
1 in. of covering B	134
½ in. of covering A inside, ½ in. covering B outside	104.6
½ in. of covering B inside, ½ in. covering A outside	108.5
½ in. of covering A inside, 1½ in. covering B outside	88.0

This table shows that in compound covering, to get the best insulating effect the better covering should be placed next to the pipe.

Fig. 13 shows the effect of compound covering, compared with single covering. Curve 1, Fig. 13, is for ½ in. of magnesia covering and varying thickness of a poor covering having a conductivity of 0.1. Curve 2, Fig. 13, is for 1 in. of magnesia covering and varying thickness of a poorer covering, such as cement with a conductivity of 0.1.

The point A on the curve represents the heat loss per linear foot of 1 in. magnesia covering. Drawing a horizontal line from this point to curve 1 would give the equivalent thickness of poorer covering necessary with ½ in. magnesia. The result shows that ½ in. magnesia covered with 1½ in. of cement has the same effect as 1 in. of magnesia.

COVERING WITH AIR SPACE

Many of the coverings used for pipes buried in the ground have an air space between the pipe and covering, or between the covering and the enclosing outer casing that protects the covering from injury. These air spaces are only effective when the temperature of the pipe is low, as in low pressure steam. As the temperature of the pipe increases the air space becomes less and less important as an insulating medium. The thickness of the air space has very little effect when the air space is ¾ in. wide or wider. In most pipe coverings this space varies from ¾ in. to 2 in. The heat loss across such an air space may be represented by the expression:

$$H = A\ (t_1 - t_a) \text{ for the condition in Fig. 14} \qquad (18)$$

where A = a constant for the transmissivity of the surfaces (it will vary with the character of the surface and temperature of the surfaces);

t_1 = Temperature of pipe in degrees, fahr.;

t_a = Temperature of the inside of covering in degrees, fahr.

The heat loss through the covering may be expressed as in equation (16); hence:

$$H = \frac{2\Pi k\ k_c\ (t_a - t_2)}{k_c \log \frac{r_2}{r_c} + k \log \frac{r_c}{r_a}} \tag{19}$$

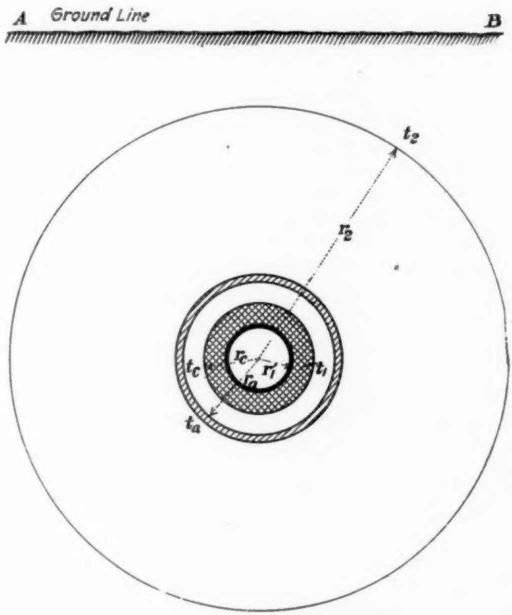

FIG. 15. STEAM PIPE BURIED DEEPLY IN THE GROUND WITH AIR SPACE OUTSIDE OF COVERING.

The covering used outside of the insulating material is usually tile and has about the same conductivity as soil and is therefore neglected. Solving (18) and (19) for t_a and equating these values we have:

$$\frac{At_1 - H}{A} = \frac{H\ (k \log \frac{r_2}{r_c} + k \log \frac{r_c}{r_a}) + 2\Pi k\ k_c t_2}{2\Pi k\ k_c}$$

Solving for H in the above equation:

$$H = \frac{2\Pi k\, k_c A\ (t_1 - t_2)}{A k_c \log \frac{r_2}{r_c} + A\ k \log \frac{r_c}{r_a} + 2\Pi k\ k_c} \qquad (20)$$

In order to solve this equation it is necessary to know the value of A.

$$A = \frac{1}{\frac{1}{k_1} + \frac{1}{k_2}}$$

where k_1 and k_2 are the transmissivities of the surfaces composing the air space. Professor Williard gives an average value of A for the air space in building materials as 1.57.

Another common arrangement is where the air space is put outside of the covering, the outer enclosing material being wood or split tile as in Fig. 15. The outer enclosing material is assumed as tile which has about the same conductivity as wet soil and is therefore neglected. The heat loss through the covering would be:

$$H = \frac{2\Pi k_c\ (t_1 - t_c)}{\log \frac{r_c}{r_1}} \qquad (21)$$

The heat loss through the air space would be:

$$H = A\ (t_c - t_a) \qquad (22)$$

The heat loss through the ground would be:

$$H = \frac{2\Pi k\ (t_a - t_2)}{\log \frac{r_2}{r_a}} \qquad (23)$$

Eliminating t_a and t_c in these equations and solving for H we have:

$$H = \frac{2\Pi k_c k\ A\ (t_1 - t_2)}{A\ k \log \frac{r_c}{r_1} + 2\Pi k_c k + A\ k_c \log \frac{r_2}{r_a}} \qquad (24)$$

In covering over air space it may be desirable to express the loss per square foot of pipe surface. Divide equation (20) by the pipe surface, $2\Pi r_1$:

$$\text{The heat loss per sq. ft., } U = \frac{t_1 - t_2}{\frac{2^{\pi}\ r_1}{A} + \frac{r_1 \log \frac{r_2}{r_c}}{k} + \frac{r_1 \log \frac{r_c}{r_a}}{k_c}}$$

In the same way equation (24) becomes:

$$U = \frac{t_1 - t_2}{\dfrac{2^{\pi} r_1}{A} + \dfrac{r_1 \log \dfrac{r_c}{r_1}}{k_c} + \dfrac{r_1 \log \dfrac{r_2}{r_a}}{k}}$$

DISCUSSION

L. B. McMILLAN: Director Allen's paper is very interesting and the equations given are essentially in accordance with the proven and accepted theories of heat transmission. However, the author himself states that full data regarding actual conditions of the soil are lacking, therefore, in view of the assumptions that were necessary, the conclusions must be regarded as generalities regarding the various factors affecting heat flow. Conclusion 1-A may be accepted without question as it is well known that the loss through insulation per square foot of pipe surface is much greater for small pipes than for large pipes.

Conclusion 3-A states that there is no practical value in burying pipes deeply in the ground. A few years ago at an Annual Meeting of the Society, the author said that if the pipes were buried deeply enough in the ground, there would be no need for insulation at all. That statement was true enough from a theoretical point of view (if buried deeply enough, the earth would heat rather than cool the pipes), but the author's present conclusion shows that the suggestion was not of practical value.

In conclusion 4-B, the author states that it is not possible to guarantee the heat loss from insulated pipes underground. However, such guarantees have been given successfully for many years and have been proven out by actual test. The reason why this is possible is that manufacturers, who are conservative, do not put much more dependence in the resistance of the heat flow offered by the ground than they do on surface resistance of a surface exposed to air. They have found by experience that the soil resistance is much less than would be indicated by the theoretical equation. The reasons why the actual resistance of the ground is less than the theoretical resistance have already been outlined in part by the author. First, he points out that all ground is more or less wet. Part of the time there is actual flow of water through the soil, and even when the soil is partially dry, there is still a limited evaporative effect which tends to absorb the heat and increase the capacity of the soil for receiving the heat emitted by the pipe. The soil has some resistance, of course, and the poorer the insulating material (the lower its resistance), the more important is the soil resistance in determining heat flow. In the case of a well-insulated pipe, the

soil resistance is much less than the insulation resistance. The author's comparison of relative effects of insulation and of soil in determining the heat loss is based on only 1 in. thick insulation. If the comparison were made with a greater thickness of insulation, the relative effect of soil resistance would be very much lower.

Much simpler equations for the transmission through combinations of materials may be based on the conception of thermal resistances and the fact that they are directly additive if expressed in proper units. The equation for flat surfaces is as follows:

$$\text{Heat Transmission (per sq. ft. per hr.)} = \frac{t_1 - t_2}{\dfrac{1}{a_1} + \dfrac{X_1}{k_1} + \dfrac{X_2}{k_2} + \dfrac{X_3}{k_3} + \ldots + \dfrac{1}{a_2}}$$

This equation is very familiar and is extensively used in connection with insulated walls. In the equation t_1 and t_2 are respectively the temperature of air inside and outside of the wall; a_1 and a_2 are surface transmission factors; X_1 and X_2 are thicknesses in in.; and k_1 and k_2 are conductivities.

It will be noted that all of the terms in the denominator are directly additive and furthermore, that each term is proportional to the resistance of heat flow in the particular item to which it refers.

A similar equation may be written for cylindrical surfaces, thus:

Heat transmission (per sq. ft. pipe surface per hr.) =

$$\frac{t_1 - t_2}{\dfrac{1}{a_1} + \dfrac{r_1 \log e \dfrac{r_2}{r_1}}{k_1} + \dfrac{r_1 \log e \dfrac{r_3}{r_2}}{k_2} + \dfrac{r_1 \log e \dfrac{r_4}{r_3}}{k_3} + \dfrac{1}{a_2} \times \dfrac{r_1}{r_4}}$$

The first and last terms involving surface resistance may be omitted in the case of insulated pipes underground.

This equation has two noteworthy advantages over the author's equation. First, the addition of another layer of material involves only the addition of another term exactly similar to those in the denominator, and, second, that inspection of the values of the different terms in the denominator shows clearly the relative insulating value contributed by each layer. Other advantages are that it gives result in terms of sq. ft. instead of linear feet, which facilitates comparisons, and that temperature may readily be calculated at any point because the temperature drop to any point is in the same proportion

to the total temperature drop, as the resistance to that point is to the total resistance.

On page 347, the statement is made that above 4 in. the heat loss per linear foot of pipe does not increase as rapidly as the size of pipe increases. A few lines further down the identical statement is made, except that this time it refers to pipe above 6 in. Both statements are correct, but mention of pipe size might be omitted entirely, for the statements apply to all commercial pipe sizes. However, the statement in the same paragraph that a 16 in. covered pipe in wet soil loses only 8 per cent more heat per linear foot than a 10 in. pipe under the same conditions is not in accordance with the author's curves. The loss from the 16 in. is shown by the

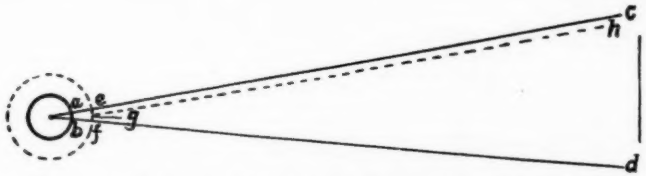

FIG. 16. DIAGRAM SHOWING THE ESCAPE OF HEAT FROM AN UNDERGROUND PIPE.

curves to be about 28 per cent greater per linear foot than from the 10 in. which is considerable. The 8 per cent applies to the condition of theoretically dry ground, which the author states is rarely obtained in practice. Furthermore, this comparison is based on 1 in. thick insulation, and the comparison would be greatly different in the case of thicker insulation.

P. NICHOLLS: There is usually difficulty in understanding why increasing the pipe to twice the diameter does not double the total heat loss. This can be best explained thus:

Consider a pipe as shown in full lines in Fig. 16. The escape of heat from a segment of its surface, *a, b,* will occur through the ever-widening pyramid *c, a, b, d.* Taking a pipe twice the diameter, as shown by the dotted line, and bisecting the segment *e, f,* one-half of it can be considered to be losing its heat through *h, g, f, d,* and the loss of heat from this half would be the same as that from the segment *a, b.* The other half, *e, g,* has only the narrow rectangle *c, e, g, h,* through which heat can escape and consequently it will have a comparatively small loss. Therefore, the sum of the whole heat lost from *e, f* will not be nearly double that from *a, b,* though each is the same fraction of its total pipe surface.

The outstanding impression that the paper leaves is the comparatively small additional savings produced by insulating the pipe,

and it is well to consider whether the mathematical assumptions are justified. As Professor Allen says, a very dry sandy soil will not be found in practice, and the lower conductivity values could be neglected.

Professor Allen assumes that a constant condition of heat loss has been reached, and neglects the time required to do this, the heat which must be stored up in the soil, and the effect of intermittent operation. The average natural temperature of the soil might be taken as 40 deg. fahr. When the pipe is put into operation, a temperature wave will be started out from it and will slowly extend, ultimately reaching a more nearly constant condition. If steam is cut off, a reverse wave will be set up, or perhaps stated more correctly, the first one will die out, and the soil will gradually cool off.

For a rough idea of what the stored-up heat will be, and without doing it in a rigidly mathematical way, Professor Allen's method may be extended. The stored heat—B.t.u.—in a foot length of soil is

$$2\pi a \int_{r_2}^{r_1} r(t-T)\,dr$$

where "a" = product of specific heat and lb. per cu. ft. of the soil, and T = the natural ground temperature. The value for t is given by Professor Allen's equations (8) or (9).

The Table given below was obtained from this, using Professor Allen's constants; pipe diam. 6 in.; insulation 1 in. thick; steam temp. 225 deg. fahr.; temp. at 40 ft. radius, 50 deg. fahr. For dry soil "A" is taken as 18, and for wet as 47. The stored-up heat is shown for natural ground temperatures of both 40 and 50 deg. fahr.

TOTAL STORED-HEAT VALUES FOR 1 LINEAR FT. OF PIPE AND TEMPERATURE AT 40 FT. RADIUS = 50 DEG. FAHR.

	Million B.t.u. Above 40 deg. fahr.		Above 50 deg. fahr.	
Condition	Dry	Wet	Dry	Wet
Total heat stored in ground with deeply buried bare pipe	2.5	6.4	1.6	4.0
Ditto—insulated pipe	1.58	4.1	0.68	1.7
Difference	0.92	2.3	0.92	2.3
Total heat stored in ground with 6 ft. deep bare pipe	1.5	3.84	0.96	2.4
Ditto—insulated pipe	0.95	2.46	0.41	1.02
Difference	0.55	1.38	0.55	1.38

HEAT LOST PER YEAR PER LINEAR FOOT OF PIPE TAKEN FROM PROF. ALLEN'S CURVES.

	Million B.t.u.	
Condition	Dry Soil	Wet Soil
Deeply buried bare pipe	0.36	1.56
Deeply buried insulated pipe	0.28	0.80
6 ft. deep bare pipe	0.42	1.92
6 ft. deep insulated pipe	0.32	0.93

Comparing the figures in the two tables would indicate that a period of not less than one year and up to several years would be required to reach the constant condition, and the effect of this on the heat loss would have to be considered. Intermittent operation would still further increase the losses.

A more rigid treatment of the problem should not, however, upset the general relationships which the paper has established, although it might change their values; but it would certainly show up to greater advantage the economy of good insulation around the pipe.

The effect of rainfall can be roughly seen by considering the total yearly fall. Assuming it to be 30 in. this would mean 12,400 lb. on the 80 ft. by 1 ft. ground area considered. If the average rise in temperature of this water, due to its passing through the heated zone, were 15 deg. fahr., it would carry away 186,000 B.t.u. during the year.

Existing values for constants are very meagre, and it is suggested that a large number could be collected quickly and at comparatively small expense by taking samples from excavations, and at the same time noting the temperatures. The conductivity could be found by the plate method, and the specific heat by getting the percentage of water, and the specific heat of the dry material.

THE AUTHOR: With reference to my change of heart in regard to pipe buried in the ground, I made the statement some years ago that it was possible that pipes, where buried deeply enough, would lose no heat. In view of the information presented here, I believe that statement was wrong. I also want to say that there was no intention in this paper to convey the idea that pipe coverings are not desirable. In fact, I think the paper will show the contrary, particularly on account of the fact, that wet soil is the soil with which we always deal and, therefore, pipe coverings are extremely desirable, and the better the pipe coverings, the more desirable they are.

In regard to testing soils, arrangements have been made with one of the universities to take up the question of the difference of conductivity of soils and to test out in a way the effect of pipe in the soil as far as it can be done.

No. 565

HEAT INSULATION FACTS

By L. B. McMillan, New York, N. Y.

Member

WHAT HEAT INSULATION IS

THE function of a heat insulating material is to retard heat flow. It is *heat* insulation whether used to keep heat where it *is* wanted as in a steam pipe or to keep heat away from where it *is not* wanted as from the cold water in a drinking water line.

It is not possible to prevent completely, by means of insulation the flow of heat as may be done by insulation in the case of electricity. All substances conduct heat to some extent. Some conduct it to a very slight extent as compared with others and it is these which are useful as insulations. However, since these materials conduct heat, even if only to a limited extent, the laws of heat flow must still be applied to determine the heat leakage and what can be accomplished by given insulation.

The conductivity k of a material is expressed in B.t.u. per sq. ft. per deg. temperature difference *between the surfaces of a* 1 *in. thick* layer per hour, with heat flow in only one direction.

By heat flow in only one direction is meant flow straight out through a flat sheet. For heat flow in more than one direction, as through a material on a cylindrical or spherical surface, the true conductivity of the material is the same and the difference in heat flow is accounted for by the increasing area of path through which the heat may flow (see Fig. 7).

Thermal conductivity is a specific property of a material in the same sense as density or weight per cubic foot is a specific property. It is not necessary to have a cubic foot of material in order to express its weight per cubic foot. The weight per cubic foot of a uniform material is the same whether there is a cubic inch or a cubic yard.

In like manner, the conductivity of a uniform material is the same whether there is a thickness of 1 in. or 10 in. or 0.1 in. and is the same regardless of the form of the material, that is, whether it is on flat or curved surface.

Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

In other words, it might be said that the true conductivity of a material in any shape or thickness is what the rate of heat transmitted per square foot, per degree temperature difference between surfaces, per hour would be if there were a large flat sheet of the material 1 in. thick, with heat applied at constant temperature to one side, while the other side was maintained at a constant lower temperature.

The *internal resistance* of a material is directly proportional to its thickness and inversely proportional to its conductivity. Therefore, 1 in. thickness of an insulation with a conductivity of 0.5 offers the

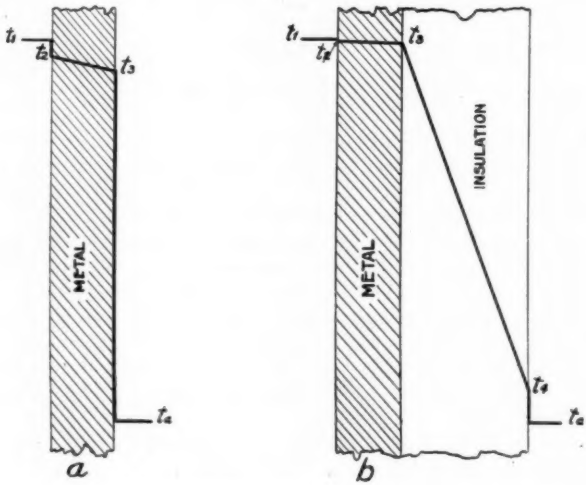

FIG. 1. DIAGRAMS SHOWING TEMPERATURE DROP FROM STEAM TO AIR.

same resistance to heat flow as 10 in. thickness of another material with a conductivity of 5.

Internal resistance $= \dfrac{\text{Thickness}}{k}$. For example, internal resistance of 4 in. brickwork $= 4/5 = 0.8$ "resistance units." What these units are called is not important—"resistance units" is as good a name as any—but it is important not to mix units in terms of inches thickness with those in terms of feet thickness or units in terms of hours with those based on 24 hours. If these precautions are observed, resistances in series—successive layers of material through which heat must pass—may be added and the reciprocal of the total resistance will be rate of heat transmission in B.t.u. per sq. ft. per hour per deg. temperature difference between points, between which total resistance has been figured.

The conductivity of wrought iron is 412 B.t.u. per sq. ft. per deg. temperature difference between surfaces per hour per 1 in. thick. However, the loss with one side of a piece of iron 1 in. thick exposed to air and the other in contact with steam at a temperature of 300 deg. higher would not be 300 x 412, but by actual experiment is known to be about 300 x 3.26 B.t.u.

The above difference is very large and the reason for such a difference requires explanation. The explanation is that the total heat loss through the 1 in. thickness is equal to the product of the conductivity 412 by the temperature difference *between surfaces,* t_2-t_3, (see Fig. 1). This is only a very small part of the total 300 deg. temperature difference in the above example.

The actual amount of heat transmitted under the above conditions is equal also to the product of a *surface transmission factor* multiplied by the temperature difference between exposed surface and surrounding air. It is the relative smallness of this surface transmission factor or, in other words, it is the fact that the air is not capable of taking up the heat as rapidly as it can be transmitted by the metal that holds back the heat and causes the drop in temperature from the outside surface to the surrounding air to be almost all of the total temperature difference between steam and air, in the case of bare surfaces. This holding back of the heat, due to the inability of the air to take up the heat as rapidly as it can be transmitted, is called "surface resistance."

Numerically, surface resistances are the reciprocals of surface transmission factors and for bare steel surfaces may be calculated from Curve 1, Fig. 2. For example, at a temperature difference of 50 deg., the surface transmission factor is 1.95 B.t.u. per sq. ft. per deg. temperature difference between surfaces and surrounding air per hour, and the surface resistance is $1 \div 1.95 = 0.513$

At a temperature difference of 300 deg. the surface transmission factor is 3.26 B.t.u. per sq. ft. per deg. temperature difference between surface and surrounding air per hour, and the surface resistance is $1 \div 3.26 = 0.307$.

The foregoing examples illustrate how surface resistances vary with temperature. They are affected also by the character of surface, whether bright or dull, by air currents, etc.

In the case of good conductors of heat, the greater part of the resistance offered to heat flow is surface resistance. In the case of insulating materials, however, most of the resistance is usually in the insulation itself and the surface resistance has less effect on the amount of heat transmitted. The surface resistance of a surface submerged in water is very small as compared with that of the same surface exposed to air. This accounts for the fact that a pipe submerged in water will transmit a vastly greater amount of heat than

the same pipe surrounded by air even though the internal conductivity of the metal is the same in each case.

A bright metal surface offers greater surface resistance than a dull or matt surface. This fact explains why the loss will be less when the insulation is covered with a bright metal jacket than if such metal jacket were not used. However, in order to dissipate the amount of heat which comes to the surface, the temperature of the metal must be raised to a higher point than if the original surface were left exposed. In other words, to force even a smaller amount of heat through a much higher surface resistance will require greater temperature head. In fact, the *decreased* heat loss may be explained by the *increase* in surface temperature. If the surface temperature is increased and inside temperature remains the same the temperature difference through the insulation is decreased; therefore, since we have the same material subjected to a lower temperature difference, the loss must be less.

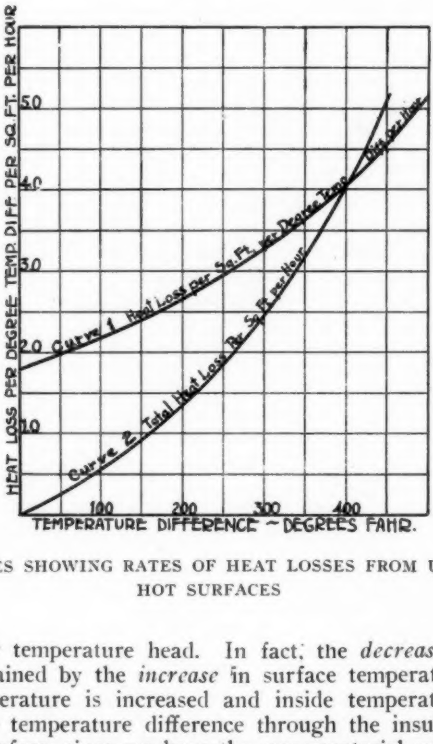

FIG. 2. CURVES SHOWING RATES OF HEAT LOSSES FROM UNINSULATED HOT SURFACES

These surface resistance phenomena also explain why a very thin layer of insulation applied over a bright metal surface will actually slightly increase the heat loss. The addition of the small amount of insulation, say 1/100 in. thick adds a small internal resistance to heat flow, but by changing the character of the radiating surface, it produces a reduction in surface resistance which more than offsets

the increase in internal resistance. However, since the surface resistance is small in comparison with the internal resistance of a really efficient insulation, if sufficient insulation is put on, the loss from the bright surface is materially decreased rather than increased.

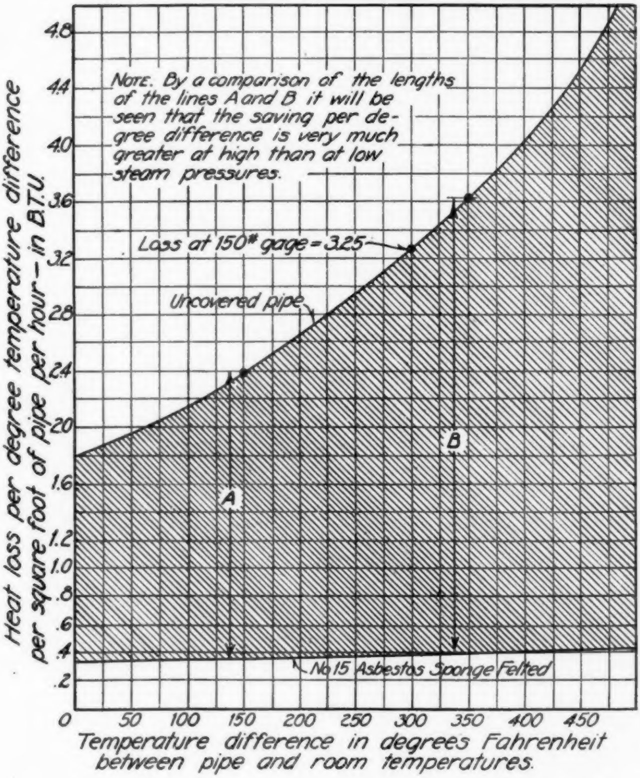

FIG. 3. CHART[1] SHOWING HEAT LOST BY BARE STEAM PIPE AND SAVING WHICH MAY BE SECURED BY USING GOOD COVERING

In the case of hot-air furnace pipes, whether they are bright or dull, the heat losses from bare surfaces are so great that it would be wasteful to leave the surfaces uninsulated. Furthermore, if a bright surface is covered with sufficient insulation the loss is brought to the same low point as if the same insulation were applied on a dull surface. Therefore, since it is this minimum of heat loss which is desired, the use of insulation is essential in either case.

[1] Reprinted from Circular No. 7. Engineering Experiment Station, University of Illinois.

The changes of surface resistance due to the effect of air circulation at the surface accounts for the increase in loss due to wind blowing on heated surfaces. The more rapidly the air is circulated over the surface the greater is its capacity for absorbing heat and the lower is the surface resistance.

WHAT HEAT INSULATION DOES

The usefulness of insulation in the saving of fuel is widely recognized, but there are other advantages due to its use which are of considerable importance and sometimes are even more important than the saving itself. Among these are increased capacity and improvement in service rendered by insulated equipment, more comfortable working conditions in the vicinity of heated surfaces and greater safety from fire and accidents.

TABLE 1. COMPARISON OF HEAT LOSSES THROUGH DIFFERENT COMMERCIAL INSULATING MATERIALS

Test Material No.		Temperature Difference—Deg. Fahr. 100	200	300	400	500
		B.t.u. per sq. ft. of pipe surface per deg. Temp. dif. per hr.				
I	85% Magnesia	0.381	0.397	0.413	0.429	0.445
II	Indented	0.483	0.509	0.549	0.603	0.666
III	Vitribestos	0.654	0.715	0.781	0.858	0.967
IV	Eureka	0.451	0.464	0.478		
V	Molded Asbestos	0.522	0.539	0.561	0.596	
VI	Wool Felt	0.400	0.421	0.442		
VII	Expanded	0.427	0.464	0.503	0.541	0.581
VIII	Carocel	0.378	0.421	0.466	0.510	0.562
IX	Serrated	0.468	0.506	0.546	0.587	0.634
X	Duplex	0.447	0.498	0.548		
XI	85% Magnesia	0.418	0.424	0.436	0.454	0.472
XII	Wool Felt	0.410	0.433	0.459		
XIII	Nonpareil High Pressure	0.402	0.412	0.426	0.444	0.465
XIV	Asbestos Fire Felt	0.711	0.749	0.795	0.845	0.901
XV	Asbesto-Sponge Felted	0.347	0.369	0.391	0.414	0.439
XVI	Asbestocel	0.429	0.454	0.493	0.544	0.609
XVII	Air Cell	0.475	0.515	0.571	0.643	0.733
XX	Plastic 85% Magnesia	0.470	0.488	0.505	0.522	0.539
XXIV	Air Cell	0.539	0.603	0.681	0.771	0.871

The rates of heat losses from uninsulated hot surfaces are shown in Fig. 2. Curve 1 shows the rate of heat loss per deg. difference per sq. ft. per hour at various temperature differences between hot surfaces and surrounding air; Curve 2 shows the total heat loss per sq. ft. per hour at any particular temperature difference. Ordinates for Curve 1 are at the left of the chart and for Curve 2 at the right of the chart.

Table 3 shows the heat loss per year from a square foot of heated surface at various steam pressures and temperatures, and the amount of coal required to replace these losses. The number of square feet required to waste a ton of coal per year at the various pressures

and temperatures is also given. For example, at 100 lb. pressure, less than 3 sq. ft. of bare surface are required to waste a ton of coal in a year. An area greater than this is exposed when a pair of 10 in. flanges is left uninsulated; therefore, the loss due to such practice is apparent. Also many surfaces at comparatively low temperatures are left uninsulated on the ground that the temper-

TABLE 2. HEAT LOSSES FROM UNINSULATED HOT SURFACES.

Ordinary steam temperatures; temperature of surrounding air, 70 deg. fahr.

Steam pressure (gage), lb.	Steam temperature, deg. fahr.	Difference betw. temp. of steam and surrounding air, deg. fahr.	Loss per sq. ft. per hr. B.t.u.	Waste of coal in lb. per sq. ft. per year	No. of sq. ft. of surface that wastes ton of coal in 1 year
0	212	142	334	293	6.82
10	240	170	425	372	5.38
25	267	197	522.5	458	4.37
50	298	228	644	564	3.55
75	320	250	737.5	646	3.10
100	338	268	820	718	2.79
150	366	296	960	840	2.38
200	388	318	1079	945	2.12
250	406	336	1184	1036	1.93

Temperatures lower than 212 deg. fahr.

Surface temperature, deg. fahr.	Dif. betw. temp. of surface and surrounding air, degree fahr.	Heat loss per sq. ft. per hr., B.t.u.	Waste of coal in lb., per sq. ft. per year	No. of sq. ft. of surface that wastes 1 ton of coal in 1 yr.
100	30	56.6	49.6	40.3
120	50	97.5	85.4	23.4
140	70	142	124.3	16.1
160	90	190	166.3	12.03
180	110	242	212	9.44
200	130	298.5	261.5	7.65

Above figures involving waste of coal are based on the following:

10,000 B.t.u. available per lb. of coal, which is equivalent to a boiler efficiency of 70 per cent, using coal with an assumed heating value of about 14,000 B.t.u. per lb.

These figures are very conservative, as both the boiler efficiency and the heat value of the coal are high—a lower boiler efficiency or inferior grade of coal would cause even a greater waste in pounds of fuel.

atures are not high enough to justify insulation. However, it will be noted that only 12 sq. ft. of surface at 160 deg. are required to waste a ton of coal per year. Surfaces which are too hot to be touched with comfort represent a serious loss of heat. The great saving accomplished by the use of a good insulation, as compared with the loss if no insulation is used, is shown graphically in Fig. 3.

In order to be suitable for a given condition, an insulation must satisfy certain requirements. It must be capable of withstanding the temperature and conditions of wear and tear imposed upon it;

it must be mechanically of such form as to permit of application in workmanlike manner to the surfaces to be insulated; it must be efficient in the preventing of heat flow and it must be durable. In general, insulating materials of laminated fibrous structure are more durable than molded forms of insulation.

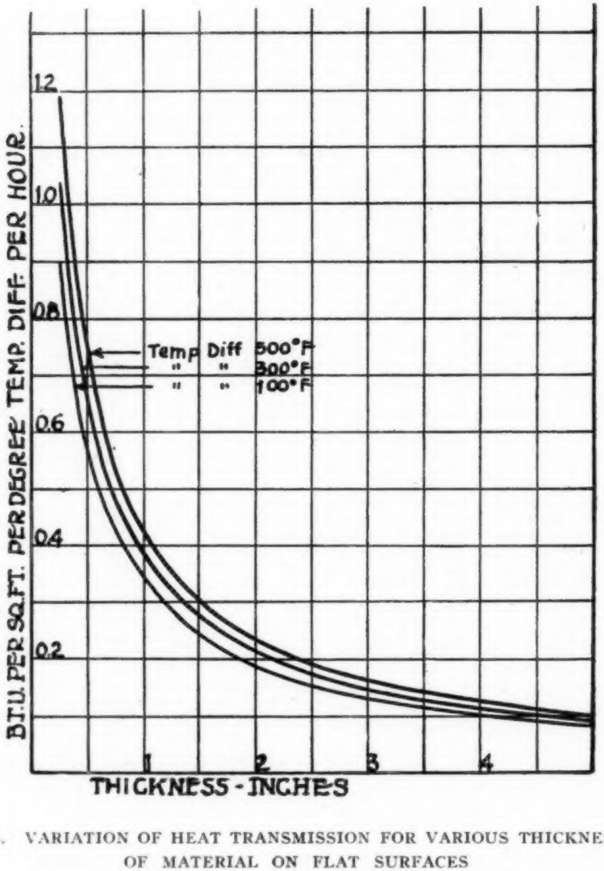

FIG. 4. VARIATION OF HEAT TRANSMISSION FOR VARIOUS THICKNESSES OF MATERIAL ON FLAT SURFACES

HOW HEAT INSULATION DOES ITS WORK—LAWS OF HEAT FLOW

Next to perfect vacuum, the most effective insulation against the flow of heat is the minute confined air space. To be most effective, the air space must be absolutely enclosed and so small that circulation cannot take place within it, nor heat radiate across it to any

appreciable extent. Even perfect vacuum would be ineffective for anything except very low temperatures unless it were broken up into small units or unless the surfaces were mirrored to prevent radiation as in the case of a thermos bottle. Therefore, the material which contains the greatest number of small confined air spaces per unit volume is the best insulator.

Heat is transmitted in three different ways; by radiation, by convection, and by conduction.

Radiation is the transmission of heat from one body to another through the agency of a wave motion in the luminiferous ether.

Radiation depends very materially upon the character of the surface which is doing the radiating. A dull black surface will radiate heat much more readily than a bright one at the same temperature. This explains why painting the surface of an insulation or finishing it with a bright sheet iron jacket decreases the heat loss.

Convection is the carrying of heat by particles of fluid in motion, the motion usually being caused by the heat itself. The air or other fluid in contact with the hot surface tends to move upward and other fluid comes in to take its place. If the circulation is in a closed space, the fluid moves down on the cool side and gives up its heat there and returns to the hot side to receive more heat. If the space is very small, there will be little room for circulation and the difference in temperature between the two sides will be so small that the velocity at which the circulation takes place will be extremely low and little heat will be carried.

Large air spaces are only effective when the difference in temperature across them is very small, because then convection is reduced to a minimum and the radiation at low temperatures is not great. However, at high temperatures, air spaces become very ineffective in preventing the flow of heat on account of more rapid circulation of air and the greatly increased radiation.

Conduction is the passing of heat from one particle of a solid body to another by actual contact. A cold body in contact with a warmer one receives heat only by conduction, the only way that heat can be transmitted through a solid body.

The manner in which insulation prevents heat flow may be summed up as follows: Placing an opaque substance over the hot surface completely eliminates direct radiation (heat will be radiated from the surface of insulation at a lower temperature, but it cannot reach this surface by radiation). Convection within the insulating material is reduced to a minimum if the material is properly constructed so that the air spaces are very small. The transmission of heat through the insulation by conduction is minimized, because, first, the solid material itself should be of low conductivity, and

second, the porous character of the material causes any heat which escapes by conduction to follow a zig zag path.

Table 1 shows a comparison of the heat losses through a number of different commercial insulating materials of approximately the same thicknesses. Table 3 shows the thicknesses and weights per linear foot of the materials referred to in Table 1. The uses for which materials are recommended by manufacturers are also given.

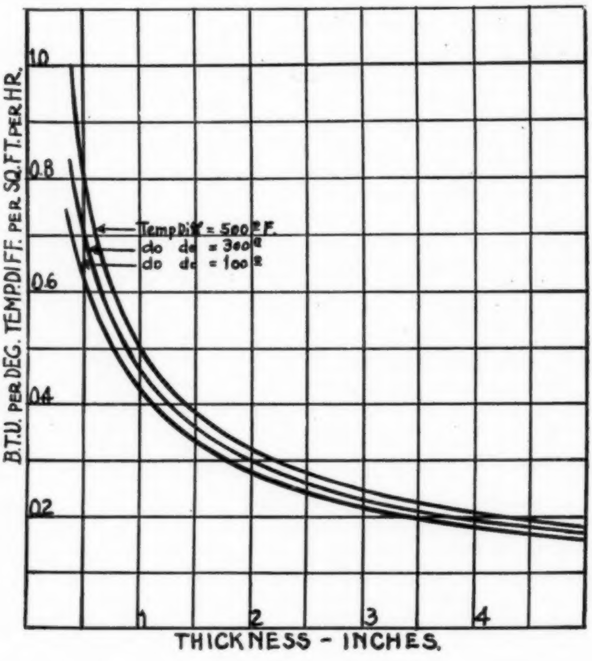

FIG. 5. EFFECT OF THICKNESS ON HEAT TRANSMISSION IN THE CASE OF PIPE WITH 3½ IN. COVERING

A detailed description of the various materials used as insulations, is not within the scope of this article, but a few words about asbestos will illustrate some interesting facts about the source of insulating value in a material. Not only are many insulations manufactured which consist almost entirely of asbestos but, on account of its fibrous character, asbestos is used as a bonding material in almost every form of manufactured insulation for high temperatures.

Asbestos is highly heat-resisting, but in its natural rock form it is solid and dense and has but little insulating value. It is not until the fibres are separated and manufactured into forms in which the fibres entrap a maximum number of finely divided air spaces that the asbestos becomes a most efficient insulating material.

Likewise, the natural rock from which magnesium carbonate is obtained has practically no insulating value. It is hard and dense and resembles marble. The high insulating value of the manufactured product is due to the process of manufacture which separates

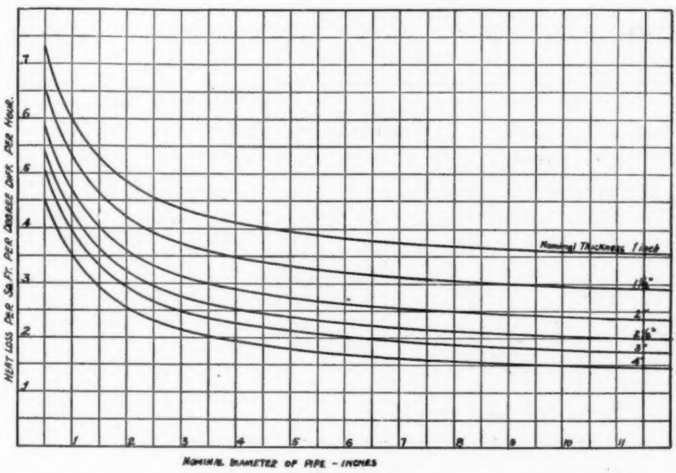

FIG. 6. VARIATION WITH PIPE SIZE OF RATE OF HEAT TRANSMISSION THROUGH A GIVEN THICKNESS OF INSULATION

the magnesium carbonate from the other ingredients in the original stone and finally gives a finished product having one-tenth of the density and less than one-twentieth of the conductivity of the natural rock.

FACTORS WHICH INFLUENCE THE FLOW OF HEAT

The four factors of greatest importance in determining the rate at which heat will be transmitted through unit area of a given insulating material are: character of material or, in other words, its conductivity; the temperature difference between the two surfaces; the thickness of insulation; the form of the insulated surface (whether flat or pipe surface, pipe size, etc.). Two other factors

of lesser importance are the finish of the surface and the velocity of air currents over the surface.

Table 1 shows a comparison of approximately equal thicknesses of a number of insulating materials. The figures in the Table and the ordinates in Figs. 4, 5 and 6, are actual rates of heat transmission per square foot of hot surface per hour per degree temperature difference between hot surface and surrounding air.

It is apparent from Table 3 that the rate of heat transmission per degree is not the same at all temperatures. However, the loss of

TABLE 3. THICKNESSES AND WEIGHTS OF INSULATION SHOWN IN TABLE 1.

Test No.	Material	Thickness, inches Actual	Apparent	Weight per Lin. Ft.	Conditions for which recommended by Manufacturer
I	85% Magnesia	1.11	1.18	2.73	High Pressure Steam
II	Indented		1.12	3.46	High Pressure Steam
III	Vitribestos	0.96	1.11	4.05	Stack & breeching linings
IV	Eureka		1.04	4.60	L. p. s. & h. w.
V	Molded Asbestos	1.25	1.26	5.53	Low & Med. pres. steam
VI	Wool Felt		1.10	2.59	L. p. s. & h. w.
VII	Expanded		1.07	3.47	High Pressure Steam
VIII	Carocel	0.99	1.06	3.06	Med. & L. p. s.
IX	Serrated	1.00	1.13	5.66	High Pressure Steam
X	Duplex	.96	1.01	1.79	L. p. s. & h. w.
XI	85% Magnesia	1.10	1.19	2.74	High Pressure Steam
XII	Wool Felt		1.01	3.73	L. p. s. & h. w.
XIII	Nonpareil High Pressure	1.16	1.23	2.96	H. p. & Superheated Steam
XIV	Asbestos Fire Felt	.99	1.09	3.75	H. p. & Superheated Steam
XV	Asbestos-Sponge Felted		1.16	4.04	H. p. & Superheated Steam
XVI	Abestocel		1.10	1.94	Med. & L. p. s. & h. w.
XVII	Air Cell	1.00	1.11	1.55	L. p. s. & h. w.
XX	Plastic 85% Magnesia	1.05	1.05	3.33	Fittings & irregular surfaces
XXIV	Air Cell		0.95	1.57	L. p. s. & h. w[1]

[1] Apparent thickness is distance from pipe surface to outer surface of insulation.

NOTE: L. p. s. = low pressure steam; h. w. = hot water.

any temperature may be found by multiplying the transmission factor found from the chart for any temperature difference between hot surface and surrounding air by that temperature difference.

Insulations are often compared in terms of their insulating efciencies. The term "efficiency" used in this connection is defined as being the percentage of the uninsulated surface loss which is saved by a given insulation. It is bare surface loss minus loss from insulated surface, divided by bare surface loss, where loss from bare surface and loss from insulated surface apply to the same area and are for the same temperature difference.

Fig. 4 shows the variation of heat transmission for various thicknesses of material on flat surfaces. It will be noted that the loss through 2 in. thick material is somewhat greater than one-half of that through 1 in. thick material, even though the figures are for

flat surfaces where the resistance of 2 in. thick material is exactly double that of 1 in. material. The reason is that the surface resistance is practically the same for the 1 in. as for the 2 in. thickness. Therefore, the resistance of 2 in. material plus one-surface resistance is not double that of 1 in. material plus one-surface resistance and rate of heat transmission is inversely proportional to total resistance.

The effect of thickness of heat transmission in the case of pipe surfaces is shown in Fig. 5. Here the loss through 2 in. thick material is even more than one-half of that through 1 in. thick than it was in the case of flat surfaces. The reason is that, in addition to the surface resistance effects, the second inch of insulation is applied over a larger area than the first so that due to the greater area offered for heat flow it does not offer as much resistance to heat flow as the first inch.

TABLE 4. PROPER THICKNESS OF INSULATIONS FOR MAXIMUM NET SAVING

Steam Pressures (lb. gage)	Steam Temperatures (deg. fahr.)	Thickness of Insulation: Pipe larger than 4 in.	Pipes 2 in. to 4 in	Pipes ⅛ in. to 1½ in.
0 to 25	212 to 267	1 in.	1 in.	1 in.
25 to 100	267 to 338	1½ "	1½ "	1 "
100 to 200	338 to 388	2 "	1½ "	1 "
Higher Pressure or Superheat	388 to 500	2½ "	2 "	1½ "
Higher Pressure or Superheat	500 to 600	3 "	2½ "	2 "

Fig. 6 shows how the rate of heat transmission through a given thickness of insulation varies with pipe size. Comparison of this chart with Fig. 4 shows that the losses through the various thicknesses on pipes are greater in each case than through the same thicknesses of the same insulation on flat surfaces, also, that the losses are greater on small than on large pipes, other conditions being the same. The reason for this may readily be seen from the illustration in Fig. 7. In the case of insulation on a flat surface, heat has only one general direction in which to flow, but in the case of insulation on a pipe, the heat has a continually widening path into which it spreads as it flows outward so that more heat will flow from a given area of pipe surface than from the same area of flat surface. The smaller the pipe the more rapidly does the path for heat flow spread out; therefore, the greater is the rate of heat loss for a given pipe area and thickness of insulation.

The effect of air currents is to decrease greatly the surface resistance. In the case of bare surfaces, this means that the losses may be increased by the effect of winds to several times the value for still air conditions. In the case of the most efficient insulations applied so that they are sealed against the effect of air blowing through the joints, etc., the maximum increase in heat transmission

due to wind velocity varies from about 10 per cent on 3 in. thick insulation to about 30 per cent for 1 in. thick insulation. These figures are necessarily only roughly approximate as the more efficient insulations are much less affected by wind velocity than the less efficient ones. In case the insulation is loosely applied so that air can circulate through the joints and crevices or between the insulation and the pipe, it is possible for wind to increase the loss upwards of 100 per cent.

Painting the surface of insulation usually decreases the loss of heat slightly and is very desirable on account of sealing the surface against circulation of air.

The thickness of insulation which it will pay to use in a given case depends upon the temperature difference between the hot surface and the surrounding air; the value of the heat to be saved by

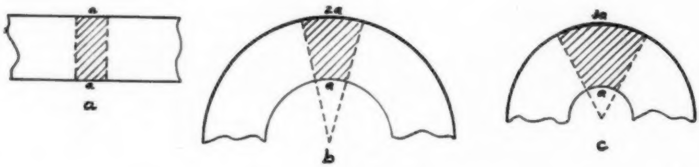

FIG. 7. AREAS OF PATHS FOR HEAT FLOW THROUGH INSULATIONS ON FLAT AND CURVED SURFACES.

insulation; the size of pipe; the kind of insulation used, and the cost of insulation. The saving should be such that the last increment of insulation put on will save enough to pay a good return on the cost of this increment of insulation. Table 4 shows the thicknesses which it will pay to use at various temperatures under average conditions. However, this table is only intended as an approximation and the proper thickness for a given condition should be checked by finding the saving in dollars per year effected by a contemplated additional thickness of insulation (see Figs. 5 and 6) and determining if this saving pays a satisfactory return on the additional cost. The need for a careful checking of this kind is especially great in case of a very expensive source of heat as from electricity, etc.

The foregoing discussion of what heat insulation is, what it does, and how it does it, logically leads to the following conclusion—the use of correct thickness of suitable insulation is one of the most important aids in heat conservation, and conservation still is, and should continue to be, a national watchword.

DISCUSSION

P. NICHOLLS: Mr. McMillan's paper is a very clearly-worded review of heat-insulation controlling principles, and the use of the conception of resistance in contradiction to that of conductivity brings out the actions more clearly. This should only be a means of conveying the idea of conductivity and emissivity, as I believe that these terms are too firmly implanted to be discarded. The paper does not, however, present any new data or values. We now have sufficient data to predict results wth an accuracy as great as the knowledge of any given conditions, but to go beyond one or two significant figures in our values there is need of further investigations. There will alway be variations in the values of the conductivity due to variations in the materials, but these need only be small. When, however, values obtained by different investigators and by different methods are compared large discrepancies are found. For example, the tests by the Bureau of Standards with the flat block method show decidedly different true conductivities to those given by the author. It is to be noted that no drop in temperature is shown between the pipe surface and the insulation. Such a drop does occur, and if taken account of would raise the author's conductivity values. The conductivities given in the paper are only mean values for a given thickness, and cannot accurately be used for different thicknesses. As conductivity increases with the temperature, the temperature curve through the insulation is not a straight line but is a curve bowed above the straight line for flat blocks, and to a less amount for pipes depending on the diameter.

It is time that the science of heat losses should be reduced to an absolute accuracy that will give the basis for constructing any curves or tables required for practical use. The two factors involved in the calculations are conductivity and emissivity, and investigations should aim to fill in all gaps so that conductivity tests by a plate method would be the only work to be done with new materials. The emissivity will follow definite laws, but the possible conditions are so various that a very close prediction will be difficult, but small variations do not affect results materially as long as the insulation thickness is not small.

The absolute conductivity ought to be expressed as in terms of the temperature so as to give a conductivity-temperature curve, and having that and the emissivity laws, it is an easy matter to obtain losses for any conditions and temperatures by means of curves. The author has styled his paper *Heat Insulation Facts*, but I must strongly dispute some of his statements. He says that "insulating materials of laminated fibrous structure are more durable than moulded forms of insulation." This is misleading, and is not borne out by experience. The representative moulded insulation is 85 per cent magnesia and the country is covered with examples of its durability running up to 25 years of continuous service. Numerous samples have been

removed from old installations, tested and found to have an efficiency not less than new material. What more severe durability tests could be applied than use on steamships and locomotives, fields which are practically monopolized by 85 per cent magnesia.

In addition to having indefinite durability, 85 per cent magnesia has the advantage that it is not damaged when water-soaked, but will dry out and be as good as new, whereas laminated coverings distort,

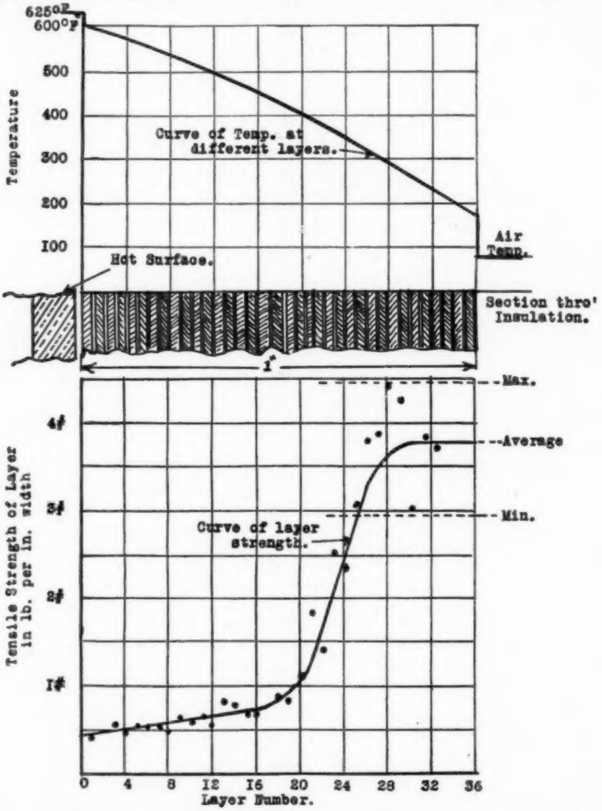

FIG. 8. THE EFFECT OF SERVICE ON ASBESTOS SPONGE COVERING.

sag, stick to the pipe and cannot be removed without destroying. Moulded covering in general can be applied to give a more finished and mechanical appearance and the same material can be used for fittings and pipes. All insulating materials to be efficient must, as the author has explained, be full of air spaces, and consequently must sacrifice strength. It is therefore expected that they will receive reasonable treatment, and if liable to damage must be encased or properly protected.

A more serious mis-statement occurs in Table 4, where 85 per cent magnesia is excluded from the superheated steam service. The only reason for its exclusion would be its non-suitability, and seeing that it has been used on higher temperatures from the time they began to be used, the contrary has been demonstrated by service.

The 85 per cent magnesia conductivity-temperature gradient is slightly less than that for laminated covering, due probably to radiation playing a larger part in the latter, so that its efficiency is better maintained at higher temperatures. Tests have been made comparing the effect of temperatures on coverings, and the results on 85 per cent magnesia and asbestos sponge were as follows, 1 in. thick covering being used in each case:

Actual temperature on pipe surface	625 deg. fahr.
Loss of weight of 85 per cent magnesia	7.5 per cent
Loss of weight corrected for original moisture	4.7 per cent
Loss of weight of asbestos sponge	10.7 per cent
Loss of weight corrected for original moisture	5.6 per cent

Thus 85 per cent magnesia lost a less percentage of weight than the sponge felt.

The 85 per cent magnesia sections did not distort or shrink and were used for further tests. The inner layers of the asbestos sponge shrunk so as to leave a gap between the longitudinal joints. The inner layers were also very brittle and a strength test gave the results shown on the curves.

The upper curve in Fig. 8 shows the temperature through the section, the horizontal being thickness. The lower diagram shows the tensile strength of the various layers, starting at the center. The original strength of the unheated layers gave results between the maximum and minimum values shown by the dotted lines. The curve shows that the first 17 layers (50 per cent of the thickness) had lost all its strength and that only 25 per cent of the thickness retained its full strength. The covering still showed a good efficiency, and if undisturbed it would undoubtedly continue to function properly.

By comparison 85 per cent magnesia is, therefore, in the superheated steam class of service, and not only has it been used in many large installations, but I know of no case where it has failed.

J. R. Allen: I would like to ask the definition of the word emissivity. There seems to be a great difference of opinion between the physicists and the engineers. The engineer uses the term to mean heat loss from a surface by conduction and radiation and the physicist uses the term to mean the unit of radiation. I think there ought to be some unanimity of practice in regard to the use of that word. It is a very convenient word as the engineers use it, but as the physicists use it I cannot see that it is of very much use.

H. C. Dickinson: The physicists use the word emissivity in that way because it is the ancient and honorable definition. That is, emissivity means a certain specific thing to the physicist, and I admit it is a very convenient term to use for the other thing. I also think

there ought to be some unanimity of practice. It is very undesirable that the same word should be used by the very same people for two different purposes. It would probably be more difficult for the physicist to drop the term, because it has a specific purpose for him, while the engineer could adopt another one. I have no other term to suggest. We have used various terms in our own work, but so far we have not found anything that is quite so short and definite as emissivity, although we won't use it because it conflicts with the accepted use of it by physicists.

THE AUTHOR: On the question of emissivity I think Prof. Allen can arrive at a definition better than I.

H. C. DICKINSON: One term for that constant that has been used sometimes is transmissivity instead of emissivity. That is almost as nice a term to use and does include by implication conduction, convection and radiation. I just want to make that suggestion.

THE AUTHOR: That is equivalent to the term "surface transmission factor," as used in the paper. It would simply be a similar term.

J. R. ALLEN: I will make a motion that in the future engineers only shall use the term *transmissivity* to mean the heat loss by radiation and convection from a surface combined.

The motion was seconded.

P. NICHOLLS: Gentlemen, I seriously object to the passing of that motion without serious consideration. The term emissivity, meaning radiation and convection, has become so universally useful that introducing another term would be confusing. There are two factors, and it seems quite permissible to use the term emissivity for the two of them. I have seen some books stating that there are certain values to that emissivity, which means two losses. I would like to have a committee look it up and report something rather than adopt another word.

H. C. DICKINSON: I should think it is a mistake, at least I do not think any physicists use the term for other than just exactly one thing. I know it has been used to some extent in engineering literature, but as far as I know, the use is rather limited, and I think it ought to be more limited.

THE PRESIDENT: All in favor of Prof. Allen's motion, manifest by the usual voting sign; contrary; the motion prevails.

THE AUTHOR: Replying to Mr. Nicholls' discussion, it is not claimed that the conception of thermal resistance should replace that of thermal conductivities, or that resistance units should be substituted for conductivities. However, the use of the resistance idea in the analysis of a heat flow problem greatly simplifies and makes very clear the reasons for the relationship between rates of loss through various thicknesses of materials and through combinations of materials. The methods used in making insulation tests are reaching a state of perfection where it is possible to check conductivities of uniform materials with a satisfactory degree of accuracy whether

the test is made on flat or cylindrical surface. The large discrepancies referred to by Mr. Nicholls as occurring between tests by different investigators, may usually be ascribed to differences in conditions under which tests were made. For example, the effect of temperature alone is often sufficient to account for the discrepancies observed. Therefore, in reporting tests of this kind the conditions and the materials themselves should be very definitely described. The temperature drop from hot surface to inside surface of insulation is very small in comparison with the total temperature drop in the case of a good insulating material. Therefore, it is not shown in Fig. 1.

In the cases of materials whose conductivities do not vary greatly with the temperature, the temperature curve through the insulation is practically a straight line for flat blocks and is decidedly bowed downward in the case of pipe insulation. Mr. Nicholls' contention that it bows upward, even in the case of pipe insulation, is contrary to the most elementary principles of heat flow through material on a cylindrical surface.

Mr. Nicholls' objection to the statement of the uses for which 85 per cent magnesia is recommended should be addressed to the manufacturers rather than to the author, as these statements were taken from their catalogues. This fact, that the recommendations are those of the manufacturers, is clearly stated in the paper.

The fact that the insulating value of one 85 per cent magnesia shown in this paper is higher than that shown in the author's paper on the *Heat Insulating Properties of Commercial Steam Pipe Coverings,* seems to disturb Mr. Nicholls very much. The new figures are a matter of record, having been published in a publication of *The American Society of Mechanical Engineers* long before this paper was written or contemplated (see Journal, A. S. M. E. November, 1918). The reasons for the difference were fully explained at that time, but since the question has been raised, the following quotation from the articles referred to will give the facts:

"The test of the first 85 per cent magnesia, results of which are given in the Transactions of *The American Society of Mechanical Engineers,* Vol. 37, pp. 944, 946, and 958, was made in November, 1914, and the sample was taken from the stock at the University Heating Station, where it had been on hand for some time, probably more than a year. Therefore, the new sample tested in February and March, 1916, represented entirely a different product embodying the improvements in manufacture which have been made in the intervening period of two or more years."

It is easy to explain why materials of identically the same chemical composition may have widely different conductivities. It is mainly a matter of the amounts of entrapped air and the sizes of the air spaces. This is explained on pages 399 and 400 of the paper.

In this paper the author strove to avoid partisan discussion and materials were mentioned by name only where reference was to previously published data. Such tables and charts were repro-

duced to illustrate points in the general discussion of the subject, and the subject was presented, not from the point of view of any one manufacturer, but in a way which should be of interest and value to everyone interested in insulation.

However, Mr. Nicholls has seen fit to criticize one particular material, *asbestos-sponge felted*, and a reply is in order. A strength test, such as that cited by Mr. Nicholls, is of no practical significance in view of the fact, that the superior durability of *sponge felted* has been amply demonstrated by the service the material has given during the period of more than 25 years it has been in use. *Sponge felted* has shown its ability to withstand superheat and has been repeatedly removed and replaced without loss of efficiency.

In fairness to Mr. Nicholls, he did state that his test showed no loss of insulating value on the part of *sponge felted*. Therefore, of what practical significance is it whether the strength is ½ lb. or 2 lb. per in. width per lamination, as long as it has been proven by long use that the material has ample strength to remain firmly in place and to withstand handling and service conditions? It is not supposed to have the tensile strength of ropes or cable. Furthermore, Mr. Nicholls neglected to say what the tensile strength of a strip of 85 per cent magnesia 1 in. wide and 0.02 in. thick would be. No doubt it was because he knew that the tensile strength of such a strip would not be measurable, even before heating, to say nothing of afterwards. This fact is of no more practical significance than Mr. Nicholls' test, as 0.02 in. of magnesia would not be used alone, but neither would one lamination of *sponge felted*.

If anyone is really interested in the comparative tensile strengths of such materials, it may be said that the average tensile strength of 85 per cent magnesia per sq. in. before being subjected to superheat, is lower than that shown by Mr. Nicholls for *sponge felted* after being so heated.

Replying to Director Allen's request for a definition of "emissivity," the author is in favor of leaving the use of this term to physicists on account of the confusion which will result if engineers use the term in one sense and physicists use it in another. The term "surface transmission factor" in the paper is clearly descriptive of the quantity referred to by Director Allen.

The term *transmissivity* proposed by Dr. Dickinson is also satisfactory, provided it is called "surface transmissivity" to distinguish it from the transmissivities of the material themselves.

No. 566

THE THERMAL CONDUCTIVITY OF HEAT INSULATORS

By M. S. Van Dusen[1], Washington, D. C.

Non-Member

INTRODUCTION

SEVERAL years ago the Bureau of Standards undertook an investigation of various physical and chemical properties of materials used in the refrigerating industry. The present paper deals with a branch of this investigation, viz., the development of a method for measuring the thermal conductivity of insulating materials. A preliminary report[2] in this connection has already been given, but it will be desirable to repeat certain portions of the former paper for the sake of unity. Particular emphasis will be laid on certain points not heretofore dealt with, and a design of apparatus will be described which it is believed will be satisfactory and convenient for testing the insulating value of commercial insulators. In introducing the subject, it may be well to discuss briefly the question of simple heat conduction in general and its relation to the insulation problem in particular.

The conduction of heat through homogeneous solid materials has been made the subject of considerable study during the past century, and in spite of the fact that exact experimental data are difficult to obtain, as shown by the mass of conflicting results, the fundamental laws of thermal conduction as expressed mathematically by Fourier and others have been amply proven to hold for the simple conditions of homogeneous solids where the structure or grain of the material is fine in comparison with its thickness or other important dimensions. For the better understanding of what follows, the terms to be used throughout the paper will be defined once for all as follows:

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[1] U. S. Bureau of Standards, Washington, D. C.

[2] Dickinson and Van Dusen, A. S. R. E. Journal, Sept., 1916.

Paper presented at the Joint Session with The American Society of Refrigerating Engineers at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920. Paper published by permission of the Director of U. S. Bureau of Standards.

1. Temperature Gradient—Temperature difference per unit distance;
2. Thermal Conductivity—Time rate of heat flow per unit area per unit temperature gradient;
3. Thermal Conduction—Time rate of heat flow per unit area per unit difference in temperature between opposite faces of a slab when the direction of heat flow is assumed to be perpendicular to the faces of the slab;
4. Thermal Resistance—The reciprocal of conduction;
5. Transmission—Rate of heat flow per unit area per unit temperature difference between the medium on one side of a wall and the medium on the other (the temperatures are assumed to be measured far enough from the material so that the effect of the latter will be inappreciable);
6. Surface Transmission—Rate of heat transfer between a surface and the surrounding air, per unit area and unit temperature difference between the surface and the air.

It follows from the definition of thermal conductivity that the time rate of heat flow H, through a flat homogeneous slab, the faces of which are at different temperatures maintained constant and uniform over the surfaces, is proportional to the area of the slab, the temperature gradient in the slab, and the thermal conductivity. This statement is given by the following equation:

$$H = KA \frac{d\theta}{dx} \tag{1}$$

Where

A = the area;
θ = the temperature;
x = the distance measured perpendicular to the surfaces of the slab;
K = the thermal conductivity of the material;
$\frac{d\theta}{dx}$ = the temperature gradient.

This equation applies only after a condition of equilibrium has been reached in which the temperature of any point in the material does not vary with time. Experimental test of this equation shows that within the limit of accuracy of measurements of this kind, the thermal conductivity, K, is dependent only upon the temperature. The conductivities of some materials increase slowly with increasing temperature, while with others the reverse is true.

Since the conductivity, K, is approximately constant for most materials through short ranges of temperature, the solution of equation (1), if K is a constant, is:

$$H = KA \frac{\Delta\theta}{d} \tag{2}$$

Where $\Delta\theta$ = the temperature difference between opposite faces of the slab;

d = the distance between opposite faces of the slab.

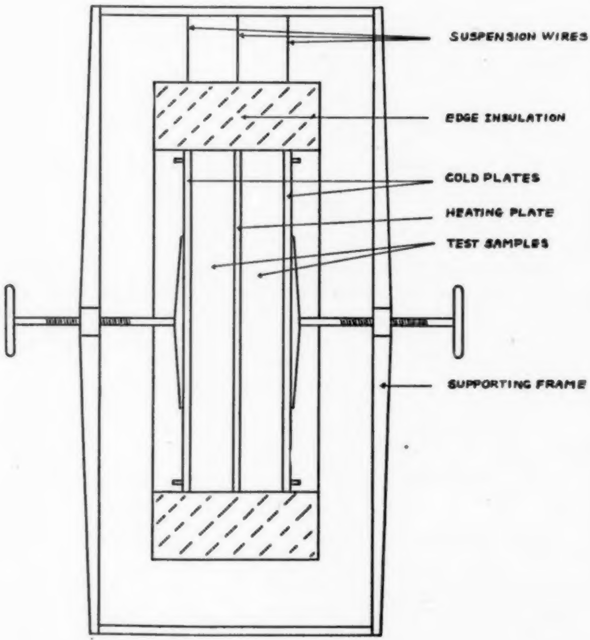

FIG. 1. DIAGRAMMATIC SKETCH OF APPARATUS FOR THE PLATE METHOD OF MEASURING THE THERMAL CONDUCTIVITY OF MATERIALS

The temperature of any plane within the slab can be calculated since the temperature gradient is constant, i. e., the relation between temperature and distance is linear.

If the wall is made up of two or more layers of different materials in contact, the temperature at all points as well as the heat flow through the system can still be found. The gradient in each material will be inversely proportional to its thermal conductivity. If the wall is exposed to air or some other medium on the two sides and

the temperature of the media on the two sides as well as the rate of transfer of heat from medium to wall on both sides are known, the temperatures throughout the wall as well as the heat transfer through the wall can still be determined. In this case there is a complete analogy with the problem of electrical resistance, the total thermal resistance being the sum of the respective resistances of the different layers. If T is the transmission, and h_1 and h_2 the respective surface transmissions on the two sides, the following equation expresses the above statement analytically:

$$T = \frac{1}{\sum_{1}^{n} \frac{d_n}{k_n} + \frac{1}{h_1} + \frac{1}{h_2}} \qquad (3)$$

$d_1\ d_2 \ldots\ d_n$ and $k_1\ k_2 \ldots\ k_n$ being respective thicknesses and conductivities of the different layers. The heat flowing per unit time through the area A in equilibrium with the temperature head $\Delta\theta$ is equal to

$$\frac{A\ \Delta\theta}{\sum_{1}^{n} \frac{d_n}{k_n} + \frac{1}{h_1} + \frac{1}{h_2}} \qquad (4)$$

Conduction in cylindrical insulators, such as pipe coverings, can be calculated just as well as conduction in the flat walls just considered. The problem, however, is not so simple as before unless the pipe is so large and the thickness of the covering so small that the curvature of the surfaces can be neglected. Even after the steady state has been reached, the temperature gradient through a pipe covering is not constant, but varies with the distance from the axis of the pipe. The rate of heat flow through a pipe covering is given by the following equation, which is readily deducible by using cylindrical coordinates:

$$H = \frac{2\ \pi\ LK\ \ \Delta\theta}{2.303 \log_{10}\left(\frac{r_2}{r_1}\right)} \qquad (5)$$

Where

L = the length of the pipe;

$\Delta\theta$ = the temperature difference between the inside and outside surfaces of the pipe covering;

r_2 *and* r_1 = the outside and inside radii, respectively, of the covering.

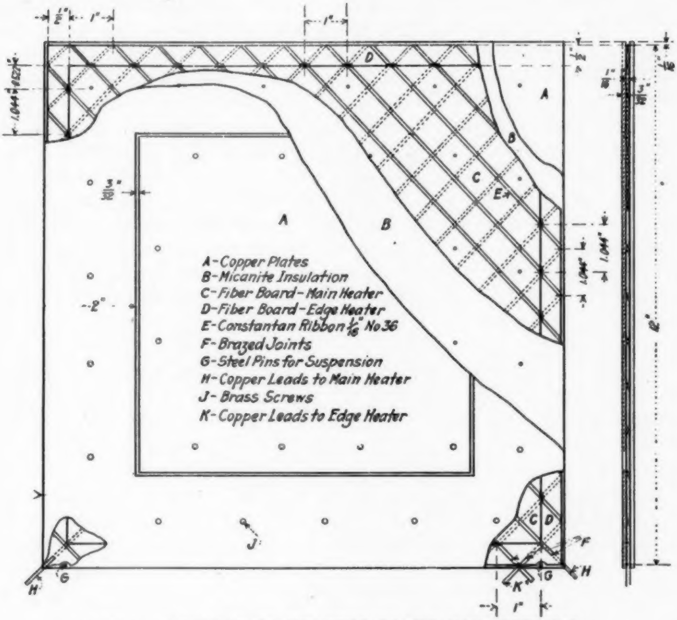

FIG. 2. DETAILS OF HEATING PLATE FOR THERMAL CONDUCTIVITY APPARATUS

If now the rate of heat transfer from the medium inside to the pipe is known, as well as that from the pipe covering to the outside air, the total heat transmission from the material inside the pipe to the air outside can be calculated without knowledge of the temperatures of the surfaces of the pipe covering. As in the case of the flat wall, it is simply a process of addition of resistances. Using the same notation as before, the total heat transfer may be shown to be:

$$\frac{2\pi L\ \Delta\theta}{\dfrac{2.303}{k}\log_{10}\left(\dfrac{r_2}{r_1}\right)+\dfrac{1}{r_1h_1}+\dfrac{1}{r_2h_2}} \qquad (6)^1$$

[1] Neglecting the thermal resistance of the pipe itself, which is relatively unimportant in the consideration of metal pipes.

In this case $\Delta\theta$ is the temperature difference between the medium inside the pipe and the air outside.

Heretofore the physicist, being primarily interested in the physical constants of materials, has concerned himself chiefly with the actual thermal conductivity of homogeneous materials. The engineer, being primarily interested in the total heat transmission from the medium on one side of a system to the medium on the other, has attacked the problem from a different standpoint and has attempted to reproduce actual conditions as much as possible without usually taking into account the different factors separately. The result has been two distinct groups of experimental investigations, particularly with reference to insulating materials, one of which offers a large quantity of data on the thermal conductivity of many materials, often not those which are of greatest importance to the engineer, while the other offers a large number of determinations of the heat transmission (from air on one side to air on the other), through various simple materials and compound walls, the results of which have often been erroneously applied in the calculation of heat transfers.

The results in either of these two groups, particularly the latter, are discordant enough because of the inherent difficulties in the measurement of heat and temperature. But more than this, there has been in many cases utter disregard of the inherent and necessary differences between the results of the two above mentioned groups of experiments. In view of the discordant condition of the data on the subject of cold storage insulation, and the apparently hopeless confusion, at the time that the present work was undertaken, between conductivity tests and transmission tests, there appeared to be urgent need for an investigation of the problem, with due regard to both points of view.

NATURE OF DATA REQUIRED

A brief glance at the methods used and results obtained in practical tests of commercial cold-storage or other insulators is sufficient to convince the impartial observer that the use of a sound standard method of test is one of the important problems in the refrigerating industry. The results obtained by different methods are in general very discordant; due not only to errors of observation, but also to the fact that with each form of apparatus a different heat transfer is measured which can not be applied indiscriminately to conditions other than those under which the experiment is made. In a great many cases the data obtained cannot be related to the actual conditions which exist in a cold-storage installation and are therefore practically useless. Furthermore, they often do not even serve as a fair basis of comparing the insulating value of different insulating materials.

The result of this unfortunate condition has led to erroneous claims by manufacturers of insulating materials which in turn have inevitably caused misunderstanding and ill-feeling. Manufacturers often send their materials to commercial laboratories for test and comparison with competitive materials. These tests are very often made by unsuitable methods and under ill-defined conditions, the result being that we have on the market several insulating materials each of which, judged by results of tests, is superior to all others as far as insulating value is concerned. It will be admitted that such a situation is very undesirable to all concerned. In order to correct

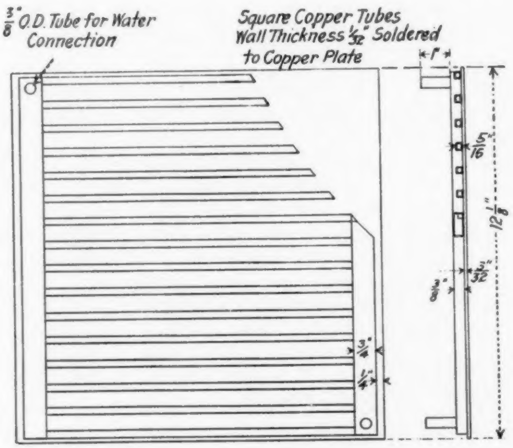

FIG. 3. DETAILS OF ONE OF THE OUTER COLD PLATES

the situation it is at once evident that the various test methods should be examined in view of their suitability for obtaining the data which are required in practical work. The method and apparatus which is capable of giving the required data with the minimum possibility of error should then be adopted as a standard method of test. Naturally accuracy greater than that required in engineering practice can be sacrificed in favor of other factors such as initial cost of equipment and rapidity of testing. After the standard method is in use, the human element can be eliminated by check measurement at different places, a procedure which is practically impossible at present.

The type of apparatus which should be selected as a standard can be settled only by a consideration of the kind of data which are needed in practical refrigeration work. A cold-storage wall is a wall having a large thermal resistance, practically all of which exists in the insulating material of which such a wall is primarily

composed. The resistance of the structural members and of the surfaces is of very much less importance. Moreover, the magnitudes of the last two factors remain the same, regardless of the insulating material within the wall. In order then to compare two insulating materials which might be placed in such a wall, it is necessary to compare them on the basis of actual internal thermal conductivity, not transmission from air on one side to air on the other, since the only surface effects which are not negligible are located on the outside and inside surfaces of the complete wall and have no relation to the insulating material. Other properties of insulating materials such as waterproofness, durability, etc., are of course very important factors for comparison but they bear no relation to the particular question discussed here.

Aside from merely comparing the thermal conductivities of different materials, it is also desirable to determine the total transmission of a complete wall. It has often been assumed that in order to calculate the heat transmission of a wall, the transmission of every single material composing the wall must be found. In the desire for tests which would appear practical, the fact that a single material very rarely makes up the entire wall has been largely lost sight of. The surface effects are in no sense properties of a single material; they are so to speak properties of a complete wall which is made up of several layers of different materials. If a surface resistance on every material composing a wall is included, the calculation of the total transmission of the wall may be affected by large errors, particularly if the calculations are based on the results of transmission tests of thin materials. In fact, it has often been the case that the transmission of a thin insulator, say ¼ in. thick, has been measured, and the figure reduced to a one-inch basis by dividing by four. In this particular instance, the error in the transmission of a one-inch layer is about 100 per cent.

It will be evident from the foregoing that the use of transmission figures on insulating material is justified only in two cases, (1) when the wall is composed only of insulating material, and the transmission of that thickness has been measured, and (2) when an insulating sheet is placed in the middle of a wide air space. The first case is never met with in practice, and the second is comparatively rare. The result in the latter is to divide one air space into two parts, each of which has approximately the same insulating value as the original air space. The final thermal resistance will be twice the original, plus the reciprocal of the conduction, i. e., the resistance of the sheet. Numerically, this is about the same as increasing the original insulation by the amount represented by the transmission of the sheet, not its conduction, provided the transmission under these particular boundary conditions has been determined. It seems more logical in this case to consider the air spaces separately, not as properties of the insulating sheet.

In the final calculation of the transmission of a complete wall, the thermal resistance at the two surfaces of the wall must of course

be known. These properties of the wall and surrounding medium are entirely separate and distinct from the thermal properties of insulating materials. Furthermore, their magnitude in comparison with the total resistance of an ordinary cold-storage wall has apparently been greatly exaggerated. As will be shown later, the combined surface effects, external and internal, on a wall having the equivalent insulation of 6 in. of corkboard is about 5 per cent of the total, judging from what data we have at present. It will be evident that in this case the surface effects need only be very roughly known and their large variation with external conditions

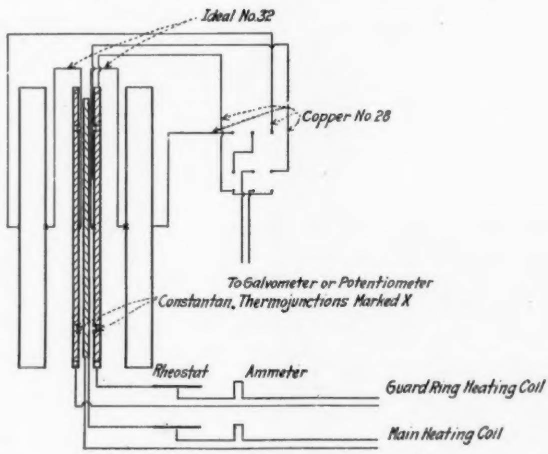

FIG. 4. ARRANGEMENT OF ELECTRICAL CONNECTIONS TO THERMO-JUNCTIONS

will have practically no effect on the heat transmission of the wall.

To sum up, then, the conclusion is reached that the absolute conductivity of insulating and other materials must be known, either for comparison of their insulating values, or for the caluculation of the heat transmission of a wall. Whenever a wall is built up by placing various layers in contact, the insulating value of each layer is dependent upon its conduction (conductivity divided by thickness), not upon its transmission, since air layers are found only at the external surfaces.

TYPE OF APPARATUS NEEDED

Measurements of thermal conductivity of poor conductors have usually been accomplished by direct methods. These methods consist in simultaneously observing the heat flow and temperature gradient in a specimen of material after a steady state has been

reached, the temperature of all points in the specimen not varying with time. From the data so obtained, the conductivity is calculated by the use of certain mathematical relations, the form of which depends on the geometrical configuration of the specimen. The simplest method is evidently one in which the samples to be tested are in form of flat slabs so that the isothermal planes are parallel to the surfaces of the slab and the temperature gradient is constant from face to face.

In the well-known "box method" of test, this condition is approximately realized if the box is large in comparison with the thickness of its walls. If the conductivity is to be determined, the temperatures of the surfaces of the wall must be measured. This can be done only by the use of thermocouples or special resistance thermometers which must be cemented onto the surfaces of each material that is tested.

Surface temperatures measured in this way in air are subject to uncertainties due to radiation effects or lead conduction, and at best it is difficult to tell whether or not the readings obtained are actually the temperatures of the surfaces. The most certain method of determining the gradient in the material is to embed the thermocouple or resistance thermometer a short distance into the material itself. To eliminate lead conduction and its consequent error in temperature measurement, the leads must be brought out for a considerable distance along the isothermal plane in which the thermometer itself is located. This is a rather difficult operation to perform on each material that is tested.

The room in which the box is located must be kept at constant and uniform temperature, and special arrangements must be made for maintaining the air inside the box at a uniform temperature throughout. Great difficulties are met with in attempting to thermostat the air in a room to a small fraction of a degree. Non-uniformity of temperature either on the outside or the inside will produce uncertain lateral heat flow in the walls of the box, and a drift in outside temperature will prevent the attainment of thermal equilibrium during an experiment. The inside heating element must be carefully shielded to prevent direct radiation, which will cause non-uniformity of temperature on the inside surfaces.

One of the greatest disadvantages of the box method as applied to the testing of insulating materials is the fact that it has led and probably will continue to lead to a disregard of the differences between conduction and transmission. Tests will undoubtedly be made at certain places without regard to surface temperatures, and the results obtained will be extremely misleading, especially if they are obtained from measurements on thin materials.

However, these sources of error and the uncertain nature of the results on single materials do not necessarily condemn the box method of test. When applied to complete walls, the method is

certainly correct in principle, and the results obtained (assuming all errors to be eliminated) are exactly the required data, viz., the heat flow through the wall. Its application, however, in this connection is very cumbersome on account of the large size of box required to eliminate corner effects, and the consequent large areas over which the temperature must be kept reasonably constant. Furthermore, a very large number of expensive experiments must

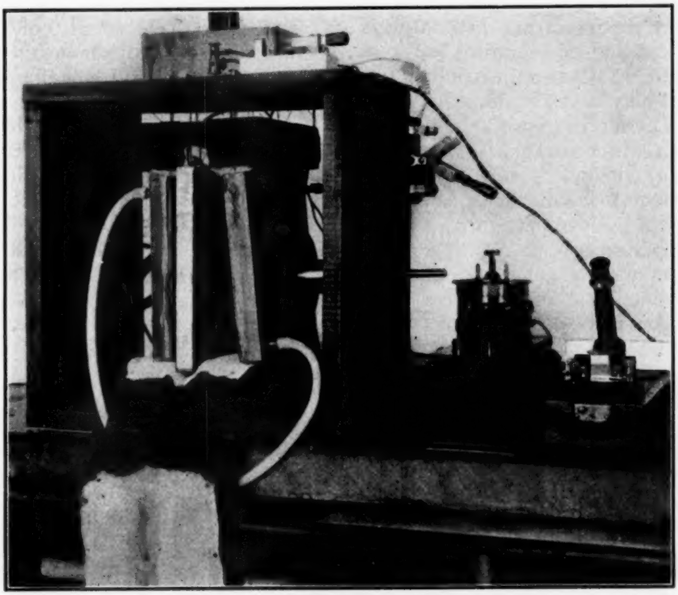

FIG. 5. GENERAL VIEW OF THERMAL CONDUCTIVITY APPARATUS, 8 IN. SQUARE

be made on various combinations in order to obtain working data. It seems fairly certain that even with the data at hand at present, it is possible to calculate the heat transmission of any ordinary cold-storage wall, at least as accurately as it can be measured directly, providing the wall has not suffered from deterioration with age or moisture absorption.

In general, it will be seen that in order to obtain accurate thermal conductivity measurements by the box method, rather complicated arrangements are required, and considerable time must be spent in preparing for each test. Furthermore, such preparations as the mounting of thermocouples, must be in the hands of experienced and throughly competent persons. It seemed desirable to simplify

the arrangement in such a way that testing could be done more rapidly and the uncertainties of temperature measurements eliminated. By removing five sides of the test box and placing highly-conducting metal plates instead of air in contact with the remaining slab, the result is virtually the plate method of test. The heating element is built into one of the metal plates and the other plate is cooled by water or brine, either of which is comparatively easy to keep at constant temperature. In an actual apparatus, instead of correcting for heat loss from the surface of the heating plate away from the insulating material, it is simpler to use two identical cooled plates, and two identical test samples, one on each side of the heating plate. The average conductivity of two samples is thus obtained, and only a small compensation for edge loss is required.

Thermocouples are installed once for all on the surfaces of the plates in contact with the insulating material, and in the case of poor conductors such as are met with in refrigeration work, the temperature difference between the plate and test specimen is insignificant compared with the temperature drop in the material. The temperature is uniform over the surfaces and no preparations aside from merely cutting samples to the proper size are necessary to conduct an experiment.

The plate method offers the following advantages over the box method:

1. Materials of high thermal conductivity instead of air are used to maintain isothermal surfaces—water or brine, instead of air, is the medium which is thermostated;
2. Temperature measuring devices are installed, once for all, in the apparatus itself;
3. Much less power is required, either for heating or cooling;
4. The operation of the apparatus is more convenient and rapid;
5. Tests on loose materials can easily be made, an operation which is very inconvenient with the box method;
6. No errors arise due to air leakage through porous materials.

PROPOSED STANDARD TESTING APPARATUS

The apparatus to be described is practically identical with that in use at the U. S. Bureau of Standards for a number of years. It is the conclusion from the experience gained that an outfit accommodating specimens 12 in. square and less than 2 in. thick is sufficient for measuring the thermal condutivity of any cold storage insulating material. No particular advantage is gained by testing larger or thicker specimens. Even if the material varies greatly it is more convenient to run several pairs of samples than to build a large apparatus which is very cumbersome to handle, expensive to construct, and requires a long time to come to equilibrium when thick specimens are tested.

Fig. 1 shows a diagrammatic sketch of the assembled apparatus. The copper plates, four in number, are suspended from the frame

by means of small piano wires. The middle plates enclose an electric heating element, details of construction of the 12 in. square heating plates being shown in Fig. 2. The heating grid, having a resistance of about twenty ohms, is built of 1/16 in. No. 36 constant ribbon, wound diagonally on a sheet of fibre board, 11 in. square, so that the winding is distributed uniformly over the entire surface. It is insulated with micanite sheets and placed between two 1/16 in. copper plates which are then held together tightly by means

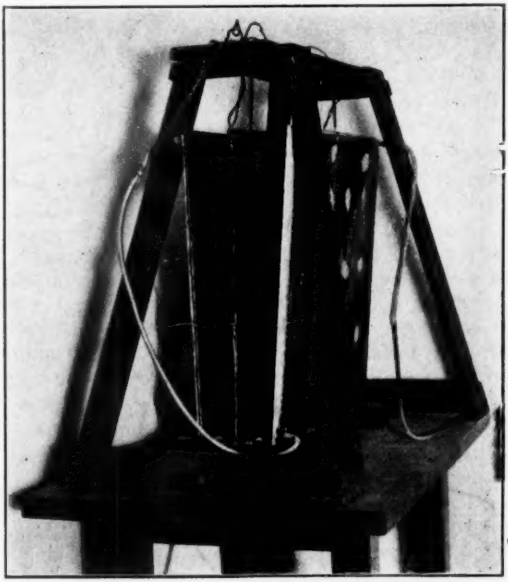

FIG. 6. THERMAL CONDUCTIVITY APPARATUS, 2 FT. SQUARE, WITH EDGE INSULATION REMOVED

of a number of copper screws passing through holes in the fibre board. Each plate has a 3/32 in. saw-cut isolating an 8 in. square in the center, as shown in the figure. This arrangement tends to minimize the heat conduction between the center square and the outer or guard ring. The two outer cold-plates (Fig. 3) are identical in construction and consist merely of ⅛ in. copper plates with water or brine circulating tubes soldered to the backs.

Thermocouples are used to measure the difference in temperature between the hot and cold plates. A fine (No. 32 B. & S. gage) constantan wire is soldered directly to the center of the surface of each plate in contact with the insulating material, the outer plates serving as cold junctions and the two surfaces of the center plates

as the corresponding hot junctions. The temperatures of the plates, as will be shown later, are sensibly the same as the temperatures of the surfaces of the test material in contact with them, providing the test material is not too good a conductor of heat. Each wire is led off from the center in a small groove cut in the surface of each plate. The copper leads to the measuring instrument are connected directly to the middle plates and to each of the outer plates as shown in Fig. 4. In this way, the copper plates themselves form the thermo-junctions with the constantan wires. Since no appreciable temperature gradient will be present in the heating plates, the junctions on those plates may be placed on the inside next to the heating grid. This eliminates the necessity of cutting grooves on the outside surfaces to accommodate the wires, but on the other hand, the junctions are not conveniently accessible.

To compensate for heat loss from the edges of the heating plate, an auxiliary heating element consisting of ribbon similar to the main heating grid is wound, as shown in Fig. 2, on a hollow square of fibre board ½ in. wide around the edges of the plates. A small auxiliary current can be regulated in this heater in order to maintain the guard ring at the temperature of the inner square Auxiliary thermocouples, the junctions of which are placed on each side of the saw-cut at the corners of the inner square, enable this adjustment to be effected. When the auxiliary thermocouples indicate a zero temperature difference across the saw-cut, no lateral flow of heat can take place either in the central square or the hollow square surrounding it.

Fig. 4 gives a diagram of the electrical connections. A reliable ammeter is used to measure the current supplied to the main heating grid and some form of potentiometer outfit to measure the electromotive forces of the thermocouples. The galvanometer used with the potentiometer can also be used as a direct deflection instrument, but this requires that all the couples have the same resistance. Furthermore, the galvanometer calibration is subject to change so that it is desirable to use a null method of measurement. The relation between the thermal electro-motive-force of the thermocouples and the temperature is taken from a calibration of a thermocouple of the same material, i. e., No. 32 constantan wire against pure copper wire.

To determine the actual rate of energy supply per unit area to the inner squares of the heating plates, the resistance per unit area of the heating grid in that region is computed from the measured resistance of the metallic ribbon per unit length, its width and spacing. This is equivalent to determining the length of ribbon over the center square and one-half the area of the saw-cut, multiplying this length by the resistance of the ribbon per unit length, and dividing the product by the area of the center plus one-half the saw-cut. The rate of electrical energy supply per unit area to each slab of test material is evidently equal to one-half the ordinary expression for power in electrical units, viz., I^2R, provided the

effective insulation on each side of the heating plate is the same. The quantity R in this case is not the total resistance of the heating grid, but its resistance per unit area of surface covered. The temperature coefficient of resistance of the constantan ribbon used for the heating grid is so small that R remains practically constant throughout the range of temperature in which the apparatus can be used.

The two outer cold plates are kept at constant temperature by allowing water or brine to flow through them in sufficient quantity to carry off all the heat supplied without becoming appreciably heated. The cooling liquid must be kept at a fairly constant temperature during an experiment, otherwise a condition of equilibrium is never reached. If water is used, an apparatus for automatically mixing hot and cold water in the proper proportions will be found

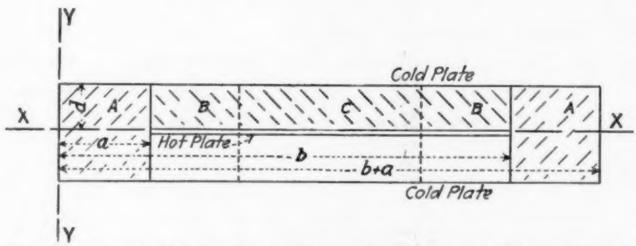

FIG. 7. CROSS SECTION OF APPARATUS USED FOR MEASUREMENT OF TEMPERATURE DISTRIBUTION

convenient to furnish a constant temperature supply, but in a great many places the tap water has a fairly constant temperaure and no thermostatic devices need be employed.

EXPERIMENTAL PROCEDURE IN ROUTINE TESTING

Two identical flat samples of insulating material are prepared and placed in the apparatus, one on each side of the central heating plate. Enough pressure is applied to insure a good contact between the specimens and the copper plates, but not enough to cause an appreciable diminution in the thickness of the samples. The heating plates are then heated up rapidly with a fairly large current to a temperature somewhat above the final equilibrium temperature desired. The current is then reduced to a value which will maintain the hot plate at about the desired temperature. This value of the current is calculated from the estimated conductivity and the thickness of the samples being tested. When a condition of approximate equilibrium has been established a small current is regulated in the auxiliary guard-ring heating coil until the thermocouples between the inner squares and the guard-rings of the heating plate

give no deflection of the galvanometer. This current must be adjusted from time to time during the experiment since the temperature of the hot plate is slowly changing as equilibrium is being approached.

Under equilibrium conditions, the average thermal conductivity of the two specimens is given by the following expression:

$$K = \frac{I^2 R d}{J \Delta\theta} \tag{7}$$

where

K = thermal conductivity;
I = current;
R = resistance per unit area of surface;
d = average thickness of sample;
$\Delta\theta$ = average temperature difference between hot and cold plates;
J = electrical equivalent of heat (4.183 Joules = 1 Calorie).

APPARATUS USED IN THE PRESENT WORK

The apparatus used in the present work will not be described in detail, since it is almost identical with the proposed standard form already described. Two different sizes of outfits were used, one capable of accommodating specimens 8 in. square and up to 1½ in. thick, and the other 24 in. square and up to 3 in. thick. Figs. 5 and 6 are photographs of the installations as they were actually used. In operation, the edges were insulated with 2 in. of corkboard upholstered on the sides in contact with the edges of the plates and test sample, so as to prevent air circulation at the edges. Even with no edge insulation whatever, the small apparatus gave practically the same value on specimens less than 1 in. thick as it did with the edge insulation in place. The cooling water was furnished from an automatically thermostated supply and was constant to much better than 0.1 deg. cent. The temperature of the cold water was generally 20 deg. cent., and in routine measurements the heating plate was maintained about 20 deg. cent. higher. Measurements were made to the nearest tenth of a degree although a change of less than half this amount could be detected with the particular galvanometer in use. Copper-constantan thermocouples have a thermoelectric power of about 40 microvolts per degree cent. in this range, so that 0.1 deg. corresponds to about 4 microvolts. The thickness of the samples was usually determined by measuring the average distance between the plates when the specimen was in place rather than by direct measurements of the specimens, especially if the material was slightly compressible.

FACTORS AFFECTING ACCURACY

A considerable number of special experiments as well as a theoretical analysis have been made with the object of determining, if possible, any systematic errors which might be present in the type of apparatus used. The possible sources of error can be summed up as follows: (1) errors in the measurement of power supplied; (2) errors in the measurement of temperature gradient, involving both temperature and thickness; and (3) thermal leakage.

The measurement of power supplied involves not only a measurement of the current flowing but also a knowledge of the resistance *per unit area* of the inner square of the heating plate. Measure-

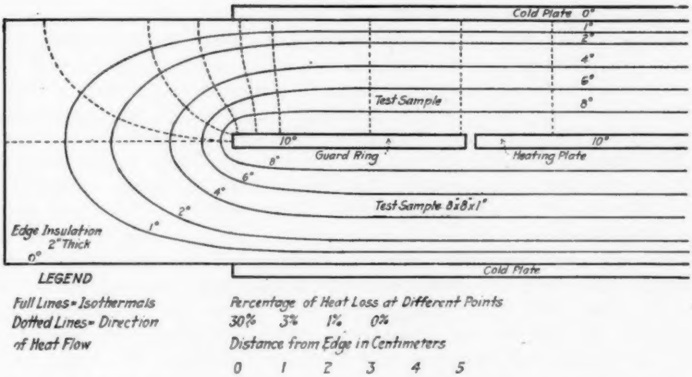

FIG. 8. RESULTS OF TEMPERATURE DISTRIBUTION MEASUREMENTS MADE WITH APPARATUS SHOWN IN FIG. 7

ment of the current to the required degree of accuracy is of course a simple matter. There is, however, some possibility of a small systematic error in the calculation of the effective resistance of the inner square of the heating plate, due to the presence of the saw-cut. The fact that such an error is within the limit of precision of the apparatus has been demonstrated by testing the same material in both the large and the small apparatus. The results of such experiments show no systematic differences of as much as 2 per cent, which is better than can be reproduced with most materials of the class. Obviously this agreement would also be obtained if each instrument were affected with the same error in the same direction, but the probability is that this is not the case, since the two have quite different dimensions. In fact it is quite probable that the error introduced in this way is less than 2 per cent but there is no way of checking it up, since the materials dealt with cannot in general be relied on as close as this, even if their respective densities are specified.

The measurement of temperature gradient, i. e., temperature difference per unit thickness, presents no difficulties if very poor conductors like cold storage insulators are dealt with. For a material having a conductivity of less than 0.0002 calorie sec.$^{-1}$ cm.$^{-1}$ deg.$^{-1}$ (14 B. t. u.), it is sufficient to measure the temperature difference and distance between the hot and cold plates. The temperatures of the plates will be sensibly the same as those of the surfaces of the material in contact with them. Even if the plates were separated from the material by a small distance, say 0.5 mm., the gradient through the material would be nearly the same as the average gradient between the plates, since the narrow air layers would have about the same thermal resistance as the same thickness of insulating material.

With increasing conductivity of test material, the surface contact resistance becomes of increasingly greater relative importance unless the thickness of the specimens is increased in proportion or special precautions are taken to insure better thermal contact. With the form of apparatus which has been described, it was impossible to test samples of better conductors of sufficient thickness to make the contact resistance negligible. In view of this, it became necessary to measure temperatures within the material itself, or at least to measure the actual temperatures of the surfaces. This has been accomplished by placing thermocouples made of very fine wire in small grooves scratched into the surfaces of the material, or by simply cementing the couple onto the surface and covering the whole with a thin sheet of insulating material. Thermocouples constructed of No. 36 copper and constantan wires are used, the junctions being brazed and flattened to a thickness of about 0.1 mm. This method of measuring the temperature difference has been found satisfactory for materials having a conductivity of 0.001 calorie sec.$^{-1}$ cm.$^{-1}$ deg.$^{-1}$ (70 B. t. u.) or less. For better conductors than this, the entire apparatus is not well adapted.

The most elusive source of error in this work as well as in all calorimetric measurements, is thermal leakage. Heat loss from the edges of the heating plate itself is compensated for by the heating coil on the edges, but the latter evidently cannot entirely compensate for lateral flow of heat within the test material. In other words, the measurement may not be made under the assumed condition that all the heat generated in the inner square of the heating plate is flowing straight across the test material, the isothermal planes being parallel to the conductimeter plates, and the lines of heat flow perpendicular to them. This condition will evidently be approached as the ratio between area and thickness of the test material is made indefinitely large, but it cannot be said offhand how small a ratio can be safely used, or how narrow a guard ring will make the thermal leakage negligible.

Measurements of the conductivity of different thicknesses of the same material show no evidence of edge heat loss. This has been

tested in the small apparatus on samples ranging from 1 cm. to 4 cm. in thickness, the conductivity as measured being independent of the thickness within the limit of precision, i. e., about 2 per cent. The heat loss from the portion of the material actually being measured (the inner square) expressed as a percentage of the total heat flow across the inner square, will evidently increase rapidly with decreasing ratio of area to thickness, the width of the guard ring remaining constant, since the absolute value of the heat loss is increasing and that of the perpendicular flow is decreasing. In

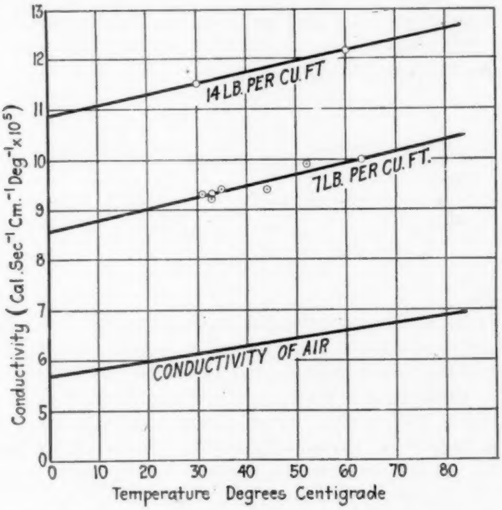

FIG. 9. THERMAL CONDUCTIVITY OF CORKBOARD, SHOWING VARIATION WITH TEMPERATURE

view of this, it would seem that the favorable evidence offered by tests of different thicknesses would be fairly convincing. In order, however, to check this independently of the other variable factors which are involved in varying the thickness and also to get some information in regard to the design of new apparatus, it was thought desirable to attempt some sort of a calculation of the temperature distribution between the plates, as well as the heat flow in different directions in that region.

Fig. 7 shows a sketch of the cross section of the type of apparatus which has been described. *A* represents the edge insulation, *B* and *C* the test specimen, the ring *B* acting as a guard to the center portion *C*, which is the portion on which the measurements are made. The

temperature distribution in this system will evidently be symmetrical about the heating plate. Let one side of the latter coincide with the X axis, and let the Y axis be the outer left edge of the edge insulation. For simplification, it will be assumed that the cold plate is at room temperature and that the edge insulation consists of the same material as the test specimens. The latter assumption corresponds approximately to working conditions when insulating materials are being tested, and when better conductors are tested, it will correspond to a condition less favorable for heat losses, since the edge insulation consists of very poorly conducting material. If now a, b, and d are distances shown in the sketch, and θ the excess of temperature of any point above the temperature of the cold plate, the temperature distribution in the region above the X axis is given by the following equation:

$$\theta = \frac{2}{b+a} \sum_{m=1}^{m=\infty} \frac{\sinh m\pi \dfrac{d-y}{b+a}}{\sinh m\pi \dfrac{d}{b+a}} \sin \frac{m\pi x}{b+a} \left[\int_0^{b+a} f(x) \sin \frac{m\pi x}{b+a}\, dx \right] \tag{8}$$ [1]

where $f(x)$ is the temperature distribution along the X axis. Along the hot plate between the points $x = a$, and $x = b$, $f(x)$ is independent of x and is equal to θ_1, the temperature difference between the plates. Between the points $x = 0$ and $x = a$, and the points $x = b$ and $x = b + a$, $f(x)$ is unknown, although it is fixed by the system and cannot be varied arbitrarily. In order to make use of the equation, the temperature distribution in this range was measured by means of thermocouples inserted at different points in the edge insulation along the X axis. The integrations called for in the equation were performed graphically and the temperature calculated as a function of x and y.

The result of this calculation as applied to the small apparatus is shown in Fig. 8. One-half of the section is shown, since the other half will be symmetrical. The numerical constants used were as follows: $a = 5$cm.; $b = 25$ cm.; $d = 2.5$ cm.; and $\theta^1 = 10$ deg.

The isothermal lines corresponding to every 2 deg. are shown and it will be noted that they are practically horizontal over a con-

[1] This equation is the solution, under the particular boundary conditions specified, of the equation:

$$\frac{\delta^2\theta}{\delta x^2} + \frac{\delta^2\theta}{\delta y^2} = 0$$

which is the general differential equation for steady heat flow in two dimensions. The heat flow in the direction of the Z axis, i. e., in the direction perpendicular to a thin section, has been neglected, since it will evidently influence the temperature distribution in the section considered to a very small extent only.

siderably larger area than that which is being measured. The dotted lines show the direction of heat flow which are, of course, perpendicular to the isothermals.

If it is assumed as a first approximation that this distribution of temperature holds for any section of the slab cut through the center, the lateral heat loss from a central square of any size can be calculated. The approximations involved are not serious since we are concerned only with the order of magnitude of the heat loss when the latter is small.

Referring again to the figure, the heat flow away from the center across any line perpendicular to the plates is equal to the expression:

$$K\int_0^d \frac{\delta\theta}{\delta x}\,dy \quad \text{per unit perimeter} \tag{9}$$

The total lateral heat loss, H, from any inner square is given by the equation:

$$H = 4(b+a-2x)K\int_0^d \frac{\delta\theta}{\delta x}\,dy \tag{10}$$

Substituting the value of the temperature gradient $\frac{\delta\theta}{\delta x}$, obtained by differentiating equation (1), keeping y constant, and performing the integration with respect to y, the equation becomes:

$$H = \frac{8(b+a-2x)}{b+a}k\sum_{m=1}^{m=\infty}\frac{\cosh\frac{m\pi d}{b+a}-1}{\sinh\frac{m\pi d}{b+a}}\cos\frac{m\pi x}{b+a}\left[\int_0^{b+a} f(x)\sin\frac{m\pi x}{b+a}\,dx\right] \tag{11}$$

Fig. 8, showing the temperature distribution between the plates also shows the lateral heat loss at several points, expressed as a percentage of the total heat flowing across an inner square, on the perimeter of which the points are located. The figure given for the outer edge of the sample, viz., 30 per cent, has been increased by an estimation of the loss from the edges of the heater itself. The latter heat loss was estimated as 15 per cent, so that the loss from the edges of the insulating material itself is only 15 per cent. The figure for total edge loss, viz., 30 per cent, should check with the actual heat supplied to the edges by means of the edge heating coil when samples of insulating material having a thickness of 2.5 cm. are measured.

The actual edge heat supplied in such a case is about 40 per cent of that supplied in the main heating grid, but the check is satisfactory, in view of the approximations involved in the calculation. In going toward the center, however, the lateral heat loss decreases very rapidly. The actual width of the guard ring employed in the

TABLE 1 ~ RESULTS OF TESTS OF INSULATING MATERIALS ~

MATERIAL	REMARKS	THERMAL CONDUCTIVITY		DENSITY	
		K x 10	k	D	d
AIR	If no heat is transferred by radiation or convection	6.0	4.2	0.0012	0.08
CALORAX	Fluffy mineral powder	7.6	5.3	0.064	4.0
KAPOK	Hollow Vegetable fibers loosely packed	8.2	5.7	0.014	0.88
PURE WOOL		8.4	5.9	0.11	6.9
PURE WOOL		8.4	5.9	0.10	6.3
HAIR FELT	Fibers perpendicular to heat flow	8.5	5.9	0.27	17.0
PURE WOOL		9.0	6.3	0.08	5.0
SLAG WOOL	Loosely Packed	9.0	6.3	0.20	12.0
KEYSTONE HAIR	Hair felt and other fibers confined with building paper.	9.3	6.5	0.30	19.0
MINERAL WOOL	Loosely Packed	9.3	6.5	0.20	12.0
CORKBOARD	No artificial binder, low density	9.3	6.5	0.11	6.9
MINERAL WOOL	Fibers perpendicular to heat flow	9.9	6.9	0.29	18.0
COTTON WOOL	Medium Packed	10.0	7.0	0.08	5.0
PURE WOOL	Very loose packing probably air circulation through material	10.1	7.0	0.04	2.5
INSULITE	Pressed Wood Pulp	10.2	7.1	0.19	12.0
MINERAL WOOL	Firmly Packed	10.2	7.1	0.34	21.0
LINOFELT	Vegetable fiber confined with paper. Flexible and soft	10.3	7.2	0.18	11.3
GROUND CORK	Less than 1/16 inch	10.2	7.1	0.15	9.4
CORKBOARD	No artificial binder	10.4	7.3	0.16	9.9
CORKBOARD	No artificial binder	10.6	7.4	0.18	11.3
SIL-O-CEL	Pulverized	10.6	7.4	0.17	10.6
REGRANULATED CORK	About 3/16 inch	10.7	7.5	0.13	8.1
BALSA WOOD	Very light wood, across grain	10.7	7.5	0.113	7.1
BALSA WOOD	Same sample with 13 percent waterproofing compounds	11.9	8.3	0.128	8.0
COTTONSEED HULL FIBER	Loosely Packed	10.8	7.5	0.071	4.4
CABOTS QUILT	Eelgrass enclosed in burlap	11.0	7.7	0.25	16.0
FLAXLINUM	Felted vegetable fibers	11.3	7.9	0.18	11.0
FIBROFELT	Felted vegetable fibers	11.3	7.9	0.18	11.0
ROCK CORK	Mineral wool and binder	11.3	7.9	0.25	16.0
CEIBA WOOD	Across grain-untreated	11.3	7.9	0.113	7.1
BALSA WOOD	Across grain-untreated	11.9	8.3	0.118	7.4
BURRASH	Confined with cloth	11.6	8.1	0.14	8.8
CORKBOARD	With Bituminous binder	12.1	8.4	0.25	16.0

TABLE 1~CONTINUED

MATERIAL	REMARKS	THERMAL CONDUCTIVITY		DENSITY	
		K x 10	k	D	d
WOOD FELT	Flexible paper stock	12.5	8.7	0.33	21.0
LITHBOARD	Mineral Wool, vegetable fibers, and binder	13.1	9.1	0.20	12.5
BALSA WOOD	Medium Weight Wood	13.2	9.2	0.14	8.8
SAWDUST	Various	14.0	9.7	0.19	12.0
PLANER SHAVINGS	Various	14.0	10.0	0.14	8.8
WALL BOARD	Stiff Paste Board	17.0	12.0	0.69	43.0
AIR CELL $\frac{1}{2}$ INCH	Corrugated asbestos paper enclosing air spaces	15.0	11.0	0.14	8.8
AIRCELL 1 INCH	Ditto	17.0	12.0	0.14	8.8
ASBESTOS PAPER	Built up of thin layers	17.0	12.0	0.50	31.0
ZENITHERM	Infusorial earth and asbestos	17.0	12.0	0.26	16.0
85% MAGNESIA	Magnesia and asbestos	17.5	12.0	0.31	19.0
INSULEX	Asbestos and plaster blocks very porous	19.0	13.5	0.29	18.0
SIL-O-CEL	Infusorial earth, natural blocks	20.0	14.0	0.45	28.0
SIL-O-CEL	Ditto	21.4	15.0	0.50	31.0
BALSA WOOD	Heavy	20.0	14.0	0.33	20.0
FIRE FELT SHEET	Asbestos sheet coated with cement	21.0	14.0	0.42	26.0
FIRE FELT ROLL	Flexible Asbestos Sheet	22.0	15.0	0.68	43.0
CYPRESS	Across Grain	23.0	16.0	0.46	29.0
FULLER'S EARTH		24.0	17.0	0.53	33.0
ASPHALT ROOFING	Felt saturated with asphalt	24.0	17.0	0.88	55.0
WHITE PINE	Across Grain	27.0	19.0	0.50	32.0
ASBESTOS MILL BOARD		29.0	20.0	0.97	61.0
MAHOGANY	Across Grain	31.0	22.0	0.55	34.0
VIRGINIA PINE	Across Grain	33.0	23.0	0.55	34.0
OAK	Across Grain	35.0	24.0	0.61	38.0
MAPLE	Across Grain	38.0	27.0	0.71	44.0
SOLE LEATHER		38.0	26.0	1.00	62.0
RUBBER	Soft Vulcanized	42.0	29.0	1.1	69.0
TEXTAN	Rubber Composition	40.0	28.0	1.3	81.0
WHITE CELLULOID		50.0	35.0	1.4	88.0
PARAFFINE	"Parawax" melting Point 52°C.	55.0	38.0	0.89	56.0
GYPSUM PLASTER		80.0	56.0	0.74	46.0
ASBESTOS WOOD	Asbestos and Cement	93.0	65.0	1.97	123.0

K - Thermal conductivity in Cal. sec^{-1} cm^{-1} deg^{-1}
k - Thermal conductivity in Btu. per day (24 hrs.) per sq. ft. per deg. fahr. per inch thickness
k = 69700 K
D - Density in grams per cm^3
d - Density in lbs. per cu. ft.
d = 62.5 D

present experiments was 5 cm., which it will be noted was well within the limit of negligible heat loss. A guard ring of considerably less width could have been employed without appreciably affecting the accuracy of the results.

RESULTS ON INSULATION MATERIALS

Table 1 gives the results of conductivity measurements on a considerable number of insulating, as well as other materials of general interest. It will be noted that most materials which are used in cold storage insulation have more or less the same conductivity, the range being from about 6 to 9 B. t. u., most materials falling between 7 and 8 B. t. u. With so small a variation in the conductivity, it is evident that the selection of any material for a particular purpose must be influenced largely by other considerations, such as water resistance, fire hazard, workability, durability, sanitation, cost, etc., none of which have been considered in this work. Most of these factors are not susceptible of laboratory investigation, but require observations of permanent installations under working conditions over long periods of time.

No considerable work was done on the temperature coefficients of conductivity of insulating materials, since the latter are ordinarily used not far from the range in which the experiments were made. The temperature coefficient of corkboard was observed through the temperature range 20 deg. cent. to 100 deg cent., and was found to be very near that of air as might be expected from the nature of the material. Fig. 9 is a curve showing the variation of the thermal conductivity of corkboard with temperature. In the same figure, the thermal conductivity of air is plotted for comparison.

Considerable work was done on the relation between the thermal conductivity and density in different samples of the same material having different densities. It is apparently a very general belief that an insulating material merely serves as an agent to entrap air and thus permit the very low conductivity of so-called dead air to be utilized. Although no measurements have been made, the assumption is undoubtedly correct that the thermal conductivity of the cell walls of fibres of an insulating material is much greater than that of air. If this were not correct, the conductivity of certain materials of any density would be less than that of air. On account of the small area of the material composing the cell walls, however, the heat conduction along these avenues is not excessive, unless the material is too dense. According to the theory the thermal conductivity of a cellular material should increase with increasing density, at least in the range where the air pockets or cells are sufficiently small to eliminate convection. If the density of loose material like feathers is made very small, there may be considerable air circulation within the mass which will tend to increase the conduction at low densities.

This conception of heat conduction in poorly conducting fibrous or cellular materials has been well confirmed by the results of the present work, but it is nevertheless a fact that certain investigators have reached the opposite conclusion from the results of their work. The measurements of Randolph[1] on the thermal conductivity with loose wool and eider-down showed a decreasing conductivity with increasing density, even beyond the point where air circulation within the mass could possibly exist. By compressing those materials rather heavily, he was able to reduce their respective thermal conductivities below the thermal conductivity of air. In the present experiments, the attempt was made to check the measurements of Randolph on loose wool. With very light packing, the conductivity

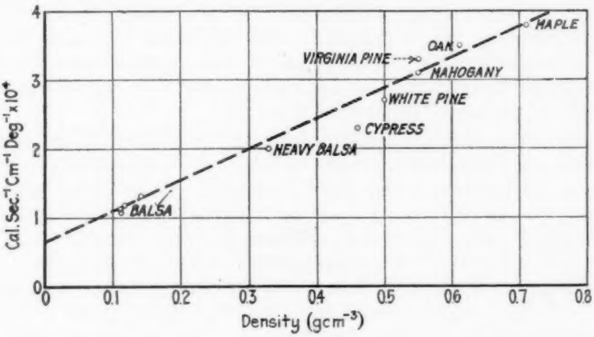

FIG. 10. THERMAL CONDUCTIVITY OF VARIOUS WOODS ACROSS GRAIN, 30 DEG. CENT.

was found to be greater than for somewhat heavier packing and the increase was attributed to air circulation among the fibres of the loose wool. As the density was increased, however, a point was soon reached where further increases in density produced no significant change in the conductivity. It was not possible in the particular form of apparatus used to increase the density much beyond this point, so that no conclusions could be drawn as to the effect of still heavier packing.

Whatever the conductivity of the wool fibres themselves may be, it is certain that the conductivity of cellulose fibres is very much greater than that of air. This is shown by the fact that all materials composed of cellulose show an increased conductivity with increased density. Figs. 10 and 11 show some of the data obtained from similar materials of different densities. It is a significant fact that the conductivities of all the various kinds of wood which were

[1] Trans. Amer. Electrochemical Society, XXL., p. 550, 1912.
Gen. Elect. Rev., 16, 120, 1913.

measured fall roughly on a straight line when plotted against density. Furthermore, the extrapolation of this line to zero density gives roughly the conductivity of air, just as might be expected. The deviation of value from a smooth curve is doubtless due to a great extent to the varying amounts of resinous substances present in the samples.

Besides serving as an agent for entrappng air, an insulating material also serves as a multiple radiation shield between the two bounding walls. Since the magnitude of such radiation has not been generally realized, a few remarks in regard to it will not be out of place here. In an air space of any width bounded by ordinary building materials such as brick, concrete, wood, paper, etc., the transmission of heat by radiation alone amounts to nearly 20 B. t. u. per day per sq. ft. per deg. fahr., even at ordinary temperatures. Upon increasing the temperature, the radiation increases rapidly. The radiation factor is the principal reason why air spaces are not good insulators. Convection plays a comparatively unimportant role when the temperature differences are small.

In order to reduce the radiation by any considerable amount, the bounding surfaces must be made of polished metals which are good reflectors and consequently poor radiators. Most other materials are very good radiators of long heat waves. It follows that even an evacuated space bounded by ordinary building materials will have a very low insulating value, equivalent, in fact, to less than ½ in. of corkboard. With air present, the insulating value will be still lower and for widths greater than about 1 in. will be practically independent of the width of the space since the radiation factor constitutes the major portion of the total heat transfer and is itself independent of the width. If a number of thin shields parallel to the bounding surfaces are placed in the air space, the heat transfer by radiation will be reduced in proportion to the number of shields. An insulating material placed in the space serves the same purpose as a large number of shields, thus eliminating the radiation almost completely, so that the low conductivity of air can be utilized.

CALCULATION OF HEAT TRANSMISSION OF WALLS

It has been previously shown that the time rate of heat transfer, H, under equilibrium conditions, through a flat wall built up of parallel layers of different materials, is given by equation (4) as follows:

$$H = \frac{A\,\Delta\theta}{\sum_{1}^{n} \frac{d_n}{k_n} + \frac{1}{h_1} + \frac{1}{h_2}}$$

where

$A =$ the area;

$\Delta\theta =$ the temperature difference between the medium on one side of the wall and the medium on the other;

$d_1, d_2, d_3, \ldots d_n$ and $k_1, k_2, k_3, \ldots k_n$ = the respective thicknesses and conductivities of the different layers composing the wall;

h_1, and h_2 = the inside and outside surface transmissions, defined as the time rate of heat transfer between the wall and the air (or vice versa) per unit area and unit difference in temperature between the wall and the air.

The thermal resistance due to imperfect contact between adjacent layers of material have not been included in the formula, since it

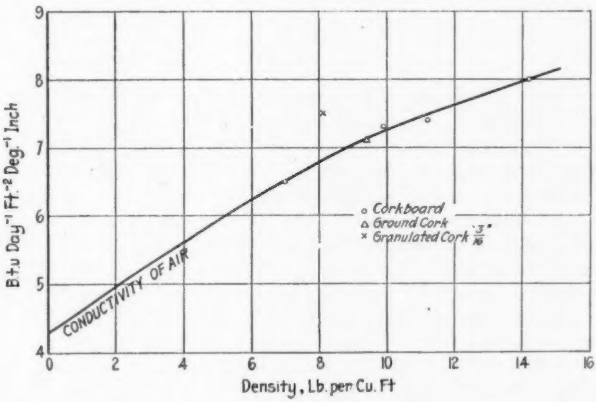

FIG. 11. THERMAL CONDUCTIVITY OF PURE CORKBOARD, 85 DEG. FAHR. SHOWING VARIATION WITH DENSITY.

has been shown that such resistances are negligibly small in comparison with the total resistance of any insulated wall likely to be met with in practice. The combined inside and outside surface resistances, however, are usually not entirely negligible although that depends upon the point of view. If the object is to save refrigeration, the surface effects can be called a small amount of cheap and variable extra insulation, the exact value of which makes no particular difference. If, on the other hand, it is desired to calculate, with the greatest possible accuracy, the heat flowing through a given wall, the surface transmissions must of course be taken into account. On account of the variability of the factors involved, it is difficult to estimate the probable accuracy of such a calculation as applied to the heat flow through a wall under actual working conditions. Besides the variability of the surface transmission itself,

which will be discussed later, the temperatures usually vary considerably, especially on the outside, so that thermal equilibrium is never reached and the wall acts as a heat reservoir. In such a case the use of the time average temperature difference existing between one side of the wall and the other involves approximations which are difficult to estimate since the problem is a complex one of variable heat flow which is practically impossible to solve except in certain special cases.

The following values of surface transmission for various surfaces have been calculated from data given by Willard and Lichty[1] :

Brick Wall	33
Concrete	31
Wood	33
Tile	26
Roofing	29

The values are given in B. t. u. per day per sq. ft. per deg. fahr temperature difference between the surface and the air. They apply under still air conditions, i. e., natural convection only. It will be noted that the values are much the same for any material which is likely to be used on the surface of a wall. Since the surface effect contributes such a small part of the total insulating value of a wall of cold storage construction, the figure 30 can be used for the inside surface transmission, regardless of what material the inside surface of the wall is made. If the external surface of the wall is exposed to the weather, the surface transmission will vary greatly with wind, rain, and sunshine, all of which depend upon local conditions, being entirely different for different exposures of the same building. Even if accurate measurements could be made for all the usual meteorological conditions, the figures obtained might be of comparatively little value, since in order to use them a knowledge of the average conditions and the worst condition would have to be obtained for any given exposure. The effect of wind and rain will be to increase the surface transmission, thus making the latter of still less importance in the calculation of the total heat transmission. On the other hand, the effect of exposure to direct solar radiation may become very large in certain cases and, of course, enormously variable. In this case, the exposed surfaces are heated above the temperature of the surrounding air and the inward heat flow may be very largely increased. Equilibrium is never established, however, and for this reason, a calculation of the heat transfer is practically impossible.

[1] Univ. of Ill. Bull. No. 102, Nov., 1917.

DISCUSSION

P. NICHOLLS: As has come out in some of our previous papers relative to heat insulation and transmission, I think that nothing is more important than to evaluate the various factors involved one at a time and the work that the Bureau of Standards is doing on absolute conductivity is the primary thing required. Nothing is more disappointing than to make tests at great cost on a complete apparatus, such, for instance, as a pipe, to measure as near as possible the factors that can be measured, to calculate the conductivity of the material, and then try to compare that conductivity with that obtained by the plate method, which one can not but believe is most accurate, and to find that he is considerably out It seems to me that what is required in heat insulation and heat measurement work for transmission through insulating materials, is to settle on a definite, very-closely-regulated method for absolute conductivity measurements. And we can presume that the work of the Bureau of Standards is trying to reach a finality.

I would like to ask Mr. Van Dusen one or two questions to clear up doubts which I have felt sometimes about the methods they are employing. First, I understand that the particular plate block testing apparatus that he shows has only comparatively recently been installed. Have the results that he has obtained by this new improved device corresponded with those which he obtained previously with the old device?

Secondly, with regard to surface drop. He says that surface drop can be neglected for insulating materials. It might be so on these lower temperatures that he uses; it is not so in connection with high temperatures, for instance, insulation on pipes, because we have been finding in tests that I am connected with that such a drop does occur. I can not give any definite figures, because the tests are under way, but approximately with 500 or 400 deg. fahr. in a pipe the drop is about 10 to 35 deg. Has Mr. Van Dusen measured that drop or determined absolutely that there is no drop, even a small one in his apparatus? Of course, when he has only 10 deg. difference the values could not be very great, nor would it be as great at a low temperature. But if you could eliminate that, if we could have the conditions to be sure of the absolute conductivity, obtain the conductivity at all temperatures accurately, be able to run up to a high temperature, we could figure the true temperature conductivity curves, and if we had those curves, had the means of easily measuring them, it would clear the air very greatly in regard to future investigations.

In the plate showing the drop in temperature through the walls, it showed no drop between the surfaces, and that such was approximately the case I can understand; but it certainly does not follow that because he gets no drop with a carefully-smoothed, level surface that he uses in his plate methods, where he makes a special block to do it, he will not get some drop on a roughly-built wall where there is an indefinite contact.

Also in the diagram he shows the temperature fall through the walls as straight lines. Should it not be that those ought to be curved lines, bowed upwards from the end points?

L. B. McMILLAN: Regarding the effect of surface resistance, I think Mr. Van Dusen was misunderstood; he did not say it was of no importance. It is of extremely little importance in the total resistance in the case of a thick wall of great insulating value. In the case of a thin insulation or no insulation at all, the surface resistance becomes a very important factor; but in the case of thick walls I think Mr. Van Dusen is correct as to the relative importance of the surface effect.

F. E. MATTHEWS[1]: In the example which Mr. Van Dusen gave you, the total resistance amounted to 6.7 in. of cork, of which 0.2 in. was surface resistance. In other words, it is one part in 33.5, if I interpreted the diagram correctly. It would be less than 3 per cent, which is well within the 10 per cent accuracy of the experiment, as I understand it.

THE AUTHOR: In regard to Mr. Nicholls' point, the apparatus which I have described has never been built in the 12 in. square size. But the apparatus which we have used is practically identical with the one described. The only differences are in details, particularly in the design of the heating coil.

As I say, the surface effect on the wall in which there are 6 in. of cork board is very small. Of course if the wall contains less, say, 4 in. or 2 in., the surface effect becomes proportionately larger; and the surface effect on a single surface is equivalent as a maximum to about 0.2 in. of cork board, or any good insulating material.

In regard to the drop between the metal plates and the insulating material in contact with them, when we test a material 1 in. thick the drop becomes about 1 per cent of the total when the conductivity increases to about twice the conductivity of cork board; that is, the drop at the surface, between the conductivity plate and the insulating material, is within the experimental error for all cold storage insulating materials.

When we test materials like ordinary wood, we are obliged to put thermo-couples on the surface of the material, or imbed thermo-couples within the material in order to get the actual temperature gradient in the material itself.

In regard to the temperature curves that I showed on the screen, the lines of course would be straight if the conductivity were independent of the temperature. The conductivity, however, does vary slightly. I hardly think you could have seen the curvature on the scale of those drawings, however.

The resistance to heat flow is directly proportional to the thickness of the material. Of course, if the total resistance between the air on one side and the air on the other is considered, then the total resistance is not proportional to the thickness. But when the temperature is measured on the surface of the material itself, then the thermal resistance is directly proportional to the thickness.

[1]269 Leonia Ave., Leonia, N. J.

No. 567

THE DISSIPATION OF HEAT BY VARIOUS SURFACES

By T. S. Taylor[1], Pittsburgh, Pa.

Non-Member

NOT long ago, while conducting a series of tests to determine the relative thermal insulating properties of asbestos, it was observed that warm water placed in a plain tin vessel cooled more slowly than when placed in a similar vessel covered with thin sheet asbestos. Since this observation was in direct contradiction to popular opinion, it seemed worth while to make some definite tests on the relative dissipation of heat by such surfaces in still air.[2]

To conduct such tests tin vessels were accordingly constructed with a lid at one end and having a diameter of 10 cm. and length of 50 cm. A cylindrical heater was made by winding No. 21 constantan wire longitudinally on an asbestos-board framework so as to slip readily into the vessels. The heater was so constructed that the same amount of heat would be developed per unit area of surface of the vessel, both sides and ends. This made it possible to maintain the temperature within the vessel at various values above the surrounding air temperatures.

The outer surfaces of the vessels were as follows: plain bright tin; tin covered tightly with 0.33-mm. (0.013 in.) sheet asbestos; tin covered loosely with three layers of 0.33-mm. asbestos; tin covered with three layers of air-cell asbestos; tin aluminum-painted; galvanized; and various dust-covered surfaces. A thermometer inserted through the side of each vessel provided means for measuring the temperature at the center of the vessel, and thermocouples of 0.005-in. copper-constantan wire were attached to the other surface of each vessel so as to measure their surface temperatures. The vessels were

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[1] Mellon Institute, University of Pittsburgh, formerly of the Westinghouse Electric and Manufacturing Co., East Pittsburgh, in whose Research Laboratory the work herein described was done.

[2] Since compiling these results the writer has learned that somewhat similar results have been observed independently by V. S. Day at the University of Illinois and were noted at the meeting of the National Warm-Air Heating and Ventilating Association, Columbus, Ohio, June 11, 1919.

Paper presented at the Joint Session with *The American Society of Mechanical Engineers* at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May 1920.

always placed horizontally in such positions in the room as to be free from unnecessary convection currents.

Observations were taken of the amounts of electrical energy, measured by ammeter and voltmeter, necessary to maintain various differences between the temperature within the vessel, as determined by the thermometer and the surrounding temperature. Surface and room temperatures were also taken at the same time. The room temperature was taken at points sufficiently distant from the vessel to be uninfluenced by it. In this manner results were obtained showing the watts dissipated per unit area for various temperature excesses (internal above room) for different surfaces.

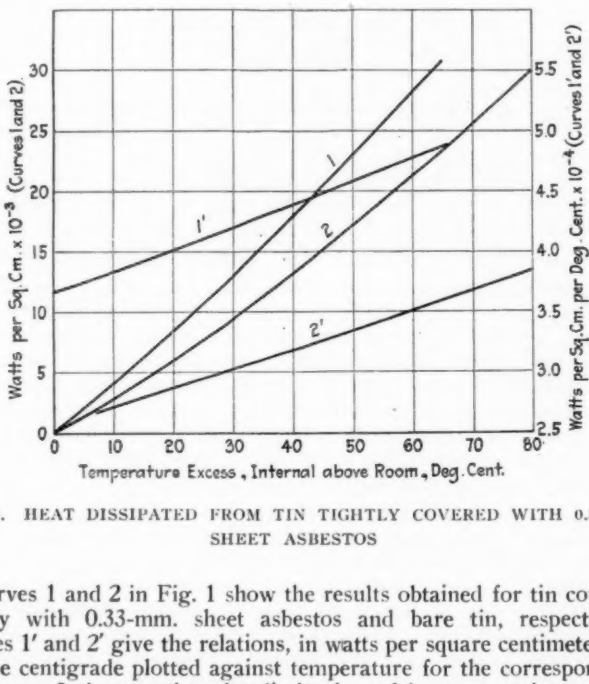

FIG. 1. HEAT DISSIPATED FROM TIN TIGHTLY COVERED WITH 0.33-MM SHEET ASBESTOS

Curves 1 and 2 in Fig. 1 show the results obtained for tin covered tightly with 0.33-mm. sheet asbestos and bare tin, respectively. Curves 1′ and 2′ give the relations, in watts per square centimeter per degree centigrade plotted against temperature for the corresponding surfaces. It is seen that the dissipation of heat per unit area per degree of temperature excess increases almost uniformly with the temperature difference over the range of temperatures used. Thus the curves 1 and 2 can be represented approximately by the relation, $W = AT + BT^2$; where W is the watts dissipated per unit area, T the temperature excess (internal above surrounding air) and A and B constants for each surface.

Table 1 gives the values of the heat dissipated by the various surfaces at corresponding temperature excesses. In addition to the surfaces listed in Table 1, results were also obtained for galvanized

TABLE 1. HEAT LOSSES FROM VARIOUS SURFACES

All values are expressed in watts per sq. cm. × 10^{-3}.

Temperature excess internal above room deg. cent.	No. 3—Bare Tin	No. 1—Tin covered tightly with 0.3-mm. asbestos	No. 1—Covered with dust	No. 3—Covered with dust	No. 5—Galvanized sheet iron	No. 6—Tin covered with 3 layers asbestos paper	No. 7—Tin, aluminum-painted
5	1.33	1.87	1.75	1.40	1.50	1.50	1.60
10	2.70	3.80	3.62	2.90	3.00	3.00	3.20
15	4.09	5.90	5.60	4.55	4.70	4.65	4.85
20	5.70	8.00	7.70	6.20	6.36	6.20	6.66
25	7.18	10.30	9.85	7.95	8.20	7.85	8.60
30	9.09	12.70	12.06	9.85	10.11	9.60	10.45
35	10.99	15.15	14.35	11.75	12.15	11.35	12.35
40	12.88	17.51	16.90	13.85	14.20	13.15	14.35
45	14.90	20.15	19.50	15.90	16.35	14.90	16.50
50	16.90	22.20	22.10	18.10	18.50	16.85	18.70
55	19.03	25.45	24.70	20.35	20.85	18.80	20.90
60	21.24	28.35	27.60	22.50	23.00	20.75	23.15
65	23.40	31.40	30.25	24.87	25.30	22.70	25.45
70	25.55			27.15	27.65	24.70	27.75
75	27.90			29.35		26.70	30.20

TABLE 2. HEAT DISSIPATED BY VARIOUS SURFACES AS COMPARED WITH THAT DISSIPATED BY BARE TIN No. 3.

Temperature excess internal above room deg. cent.	No. 1—Tin covered with 0.33-mm. sheet asbestos	No. 1—Dust covered	No. 3—Dust covered	No. 5—Galvanized sheet iron	No. 6—Tin covered loosely with three layers asbestos	No. 5—Dust covered	No. 6—Dust covered	No. 7—Tin, aluminum-painted	No. 8—Tin covered with 3 layers 0.25 in. air-cell asbestos paper
5	1.41	1.32	1.05	1.13	1.13	1.18	1.04	1.20	0.810
10	1.41	1.34	1.07	1.11	1.11	1.19	1.02	1.18	0.800
15	1.43	1.37	1.11	1.14	1.13	1.18	1.05	1.18	0.805
20	1.40	1.34	1.09	1.11	1.09	1.17	1.03	1.17	0.807
25	1.40	1.33	1.08	1.11	1.06	1.18	1.02	1.17	0.790
30	1.40	1.33	1.08	1.11	1.05	1.18	1.02	1.15	0.772
35	1.38	1.30	1.07	1.10	1.03	1.17	1.02	1.12	0.767
40	1.37	1.31	1.04	1.10	1.02	1.19	1.01	1.12	0.761
45	1.35	1.32	1.07	1.10	1.01	1.20	1.01	1.11	0.755
50	1.34	1.31	1.08	1.10	1.00	1.20	1.00	1.11	0.755
55	1.33	1.30	1.07	1.10	0.99	1.20	1.00	1.10	0.750
60	1.34	1.30	1.06	1.08	0.98	1.20	0.99	1.09	0.747
65	1.34	1.28	1.06	1.08	0.97	1.19	0.99	1.09	0.740
70			1.06	1.08	0.97		0.98	1.09	0.731
75			1.05		0.96		0.97	1.08	0.725
Mean	1.37	1.32	1.07	1.10	1.03	1.19	1.01	1.13	0.768

TABLE 3. HEAT DISSIPATED FOR A TEMPERATURE EXCESS OF 20 DEG. CENT.

All values are expressed in watts per sq. cm.

No. 1	No. 3	No. 1d	No. 3d	No. 5	No. 6	No. 5d	No. 6d	No. 7
0.0106	0.0056	0.01085	0.00630	0.00680	0.00970	0.00840	0.01060	0.00625

surface and tin loosely covered with three layers of sheet asbestos when dust-covered. Table 2 gives the relative amounts of heat dissipated as compared with bare tin for corresponding differences in temperatures. Tin covered tightly with one layer of 0.33-mm. sheet asbestos will dissipate 37 per cent more heat in still air than the bare tin. Even when both are covered with dust, such as that usually found on furnace pipes, the asbestos-covered surface will lose 23 per cent more heat than the bare one. The effect of dust on the surface is to increase the loss of the bare tin and decrease the loss of the asbestos-covered one. It requires at least three layers of 0.33-mm. sheet asbestos applied loosely on bare tin in order to dissipate no more heat than the uncovered bare tin. Three layers of air-cell asbestos on tin will permit a loss of but 75 per cent of the bare tin loss. These facts are readily shown by Table 2.

It will be observed from a study of Table 2 that the ratio for all surfaces with respect to the bare tin becomes somewhat smaller with increasing temperature excess. This indicates that if the temperature difference were high enough, very little difference would exist between the amounts of heat dissipated by each. This condition would not exist, however, until the surface temperatures were such that the heat would be lost chiefly through radiation, which for the present temperature range is not the case.

In Table 3 will be found the values of the heat dissipated per unit area per degree surface temperature excess above surrounding temperature for the particular surface temperature excess of 20 deg. cent. These results are taken from curves similar to those in Fig. 2 where the ordinates are the values of watts per square centimeter per degree centigrade surface temperature excess and the abscissæ are the corresponding surface temperature excesses. No great exactness is attributed to the results of Table 3 for the reason that no particular pains were given to the accurate measurement of the surface temperatures.

HEAT LOSSES FROM HOT-AIR PIPES

One very interesting feature about these results is their application to the loss of heat by hot-air furnace pipes. From the results in Tables 1 and 2 it is quite evident that hot-air furnace pipes lose more heat when coated with the usual sheet asbestos than when left bare. Furthermore, this difference is too great to be merely given a casual consideration, and the following brief discussion will

emphasize the point, and at the same time indicate the methods of covering pipes which will result in a saving of 25 per cent over that of the bare pipe.

Let us consider in the first place what thickness of covering would be necessary in order to insure no more loss of heat by the covered pipe than by the uncovered one. For the same temperature excess, say, 40 deg. cent. internal above surrounding air, the covered pipe loses $17.52 + 10^{-3}$ watts per sq. cm. while the bare pipe loses $12.70 + 10^{-3}$. This is seen by reference to curves 1 and 2 in Fig. 1 which show that for a covered pipe (No. 1) to lose only $12.70 + 10^{-3}$

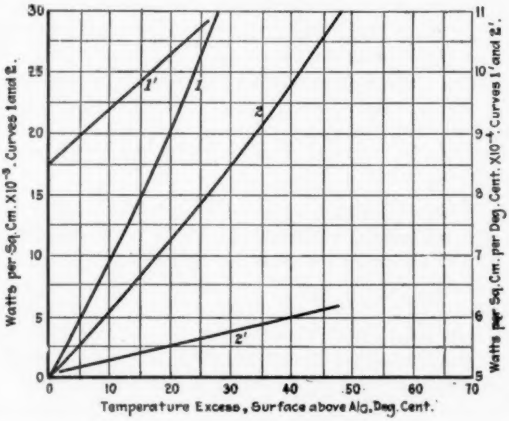

FIG. 2. HEAT DISSIPATED FROM TIN PIPE COVERED WITH ASBESTOS

watts per sq. cm. requires an outer surface temperature excess of but 12.8 deg. cent. (see curve 1, Fig. 2), and that when losing $17.52 + 10^{-3}$ watts per sq. cm. its surface temperature excess is 17.2 deg. cent. (See curve 1, Fig. 2.) Hence sufficient insulation must be added to reduce the surface temperature to the lower value, or there must be enough asbestos added to produce a drop of 4.4 deg. (17.2 — 12.8). The thickness of asbestos necessary is given by the following equation:

$$12.7 \times 10^{-3} \times 0.239 = \frac{4.4 \times 0.00035}{d} \quad \ldots\ldots\ldots \quad [1]$$

where 0.239 is the factor to reduce watts to calories and 0.00035 is the thermal conductivity of asbestos paper in calories per cm. per sec. Solving the equation for *d* gives a value of 0.51 cm., which is practically 0.2 in. While this is an approximate solution it shows that considerably more thickness of the usual insulation should be applied to hot-air pipes in order to make them as efficient as if they were left bare.

It is interesting to speculate as to the possible saving that would result by leaving the pipes bright and uncovered. Suppose there is a temperature excess, internal above surrounding air, of, say, 40 deg. cent. (72 deg. fahr.). As is shown above this corresponds to a loss of 17.52×10^{-3} watts per sq. cm. or 0.113 watt per sq. in. from the covered pipe. If we have 10 pipes 10 ft. long and 10 in. in diameter, that is, approximately 36,000 sq. in. of surface, the total loss would be $0.113 \times 36{,}000 = 4068$ watts. The total loss per day would be $4068 \times 24 \times 3600$, or 3.52×10^8 joules. One pound of coal has a heating value of approximately 12,500 B.t.u. $= 1.32 \times 10^7$ joules. Consequently the loss in pounds of coal per day would be $3.52 \times 10^8 \div 1.32 \times 10^7$, or 26.6. This would be equivalent to about 75 bu. during the heating season. The loss through a bare pipe would be equivalent to $100 \div 137$ (see Table 2) of this value, or about 54 bu. These considerations indicate, therefore, that the pipe system in question covered with 0.33-mm. sheet asbestos will lose during a winter season a quantity of heat equivalent to that obtained from 20 bu. of coal more than the same system would lose if left uncovered.

Similar calculations to those just made lead to the following results. A layer of asbestos about 0.4 in. thick, seven layers of sheet asbestos (0.013 in.) applied loosely, or three layers of 0.25 in. air-cell asbestos, will reduce the loss through the bright tin surface thus covered to only 75 per cent of what it would be if the pipe were left bare. This means that in the ordinary dwelling having a hot-air heating system, the above thicknesses of insulation applied to the pipes would result in a saving of about one ton of coal per winter season over what would be lost through a bare-pipe system and two tons over what is lost through the pipes when they are covered with the usual thin layer of asbestos.

The explanation of the larger loss through a pipe when covered with a thin layer of asbestos is based on the fact that the asbestos surface is some three or four times as great as the plain tin surface so far as molecular dimensions are concerned. The loss being due chiefly to air contact, it is readily seen that the greater the surface with which the molecules come in contact, the more heat will thus be liberated. The radiating power of the asbestos, also being larger than that of tin, will contribute an additional amount to the advantage of the asbestos as far as heat loss is concerned. The loss due to radiation, however, at these temperature differences is less than the amount lost by convection currents. Since the asbestos surface facilitates the loss of heat due to its increasing the effective molecular contacts and radiation, the surface of the asbestos and also the outer surface of the tin under the asbestos will thus have their temperatures considerably decreased and the result will be that more heat must pass through the tin and asbestos as a consequence of this condition. Therefore, when the surface of the pipe is thus changed and the heat losses increased for a given temperature gradient, it is necessary to overcome this by increasing the thickness

of the asbestos layer to such an extent that the thermal resistance of the pipe and asbestos or insulation will cut down the heat flow to the desired amount. That is, the heat loss resulting from increasing the effective area must be counteracted by increasing the thermal resistance through the addition of a greater thickness of insulation.

INFLUENCE OF AIR VELOCITY ON DISSIPATION OF HEAT

The work described under this heading was primarily undertaken for the purpose of securing data useful to engineers in designing electrical apparatus. The results obtained are for the surface of a typical end coil of a turbo-generator, but they nevertheless are of value to anyone who is interested in the problem of air cooling.

The apparatus upon which the wrapper, composed of treated cloth and tape, was placed was the same as had been previously used

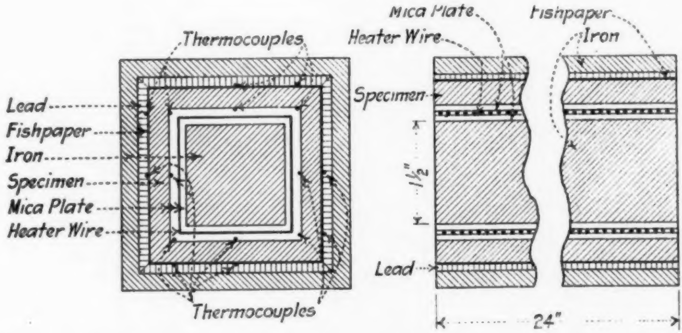

FIG. 3. APPARATUS USED IN MEASURING HEAT LOSSES IN MOVING AIR

in measuring the thermal conductivities of coil wrappers (see *Electrical World,* February 14, 1920, p. 369). An iron bar 1½ in. by 1½ in. by 24 in. was used as a core in order to secure rigidity. A layer of $\frac{1}{16}$-in. heater mica was pressed over the core and a heater wire of No. 21 constantan wound over the mica so as to have eight turns to the inch. The space between the turns was filled with asbestos cement and a second layer of $\frac{1}{16}$-in. heater mica plate was then pressed over the entire apparatus. After having been throughly dried out by sending a current through the heater wire while the entire heater was held between clamps, the apparatus was wrapped with the insulation according to definite specifications. Two thermocouples were placed on the wrapper on each side of the heater, one at the center of each side and another at the edge at corresponding positions along the heater. The thermocouple wires (0.005 in. copper and constantan) were run along the entire length of the heater, the copper ones to one end and the constantan to the other. A sketch of the heater is shown in Fig. 3.

The heater after having been thus wrapped and arranged was placed about 8 in. in front of the outlet of a blower and parallel to the opening so that the air stream fell at right angles upon it. The ends of the heater were covered with wool felt to prevent loss of heat therefrom. The outlet from the blower was of such dimensions ($2\frac{1}{4}$ in. by $2\frac{1}{4}$ in.) that the coil was completely within the air stream. Baffle plates placed in the air channel made it possible to secure a symmetrical distribution of the air stream. A small pitot tube made from a hypodermic needle was used to measure the velocity. The differences of pressure were read on a differential draft gage.

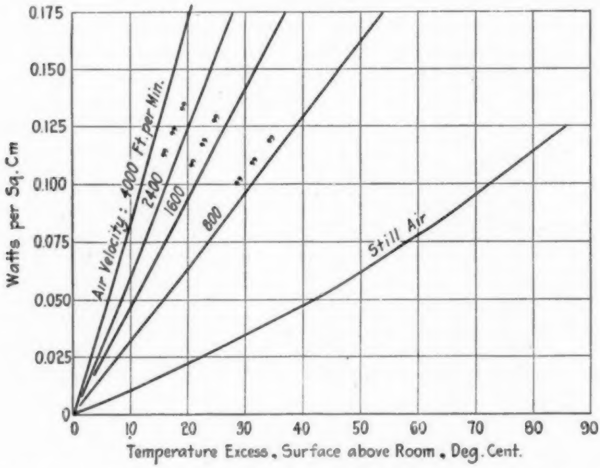

FIG. 4. EFFECT OF AIR VELOCITY ON DISSIPATION OF HEAT

Observations were also made of the air temperature and barometric pressure. The velocity of the air, V, was calculated for standard conditions, 760 mm. presesure and 25 deg. cent. temperature, by use of the formula:

$$V = \sqrt{\frac{2ghd}{d'}}$$

where g is the acceleration due to gravity, h the height of the liquid in the differential gage, d the density of this liquid, and d' the density of the air.

Measurements of the air velocity at the point in the air stream where the coil was situated showed but little variation from that for corresponding points at the opening. At least, whatever variation did exist was of the same order of magnitude as the experimental error. It was therefore assumed that the average of the velocity would be a fair value to take as the velocity of the air blowing over the coil.

The current in the heater was maintained constant and a constant number of watts were thus dissipated per unit area. Observations were taken of the excess of the surface temperature of the coil (determined from the average of the eight thermocouples on its surface) above the temperature of the impinging air for various air velocities and it was found that the heat liberated per degree excess increases approximately uniformly with the velocity over the range of velocities investigated.

In the above manner relations were determined for various amounts of heat liberated up to 0.186 watt per sq. cm. (1.2 watts per sq. in.). From these values relations were obtained between the

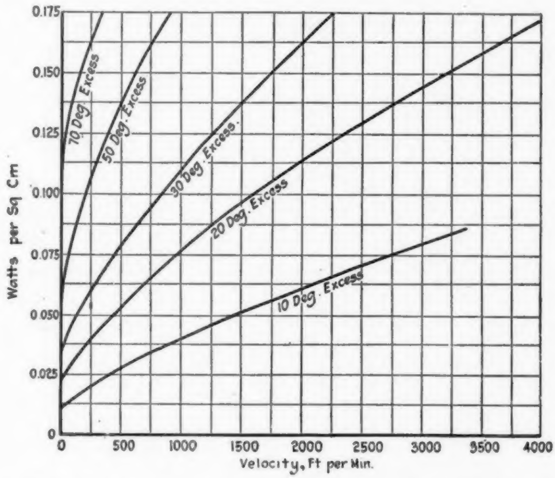

FIG. 5. EFFECT OF TEMPERATURE EXCESSES ON DISSIPATION OF HEAT

watts dissipated per square centimeter and the corresponding temperature excess of the surface above air temperature for various air velocities. The curves in Fig. 4 show the watts dissipated per square centimeter and corresponding temperature excesses for air velocities of 800, 1600, 2400, and 4000 ft. per min. For still air it is seen that the amount of heat liberated per degree of temperature excess increases with increasing temperature excess. On the contrary, it is seen that the watts liberated per unit area per degree excess is practically constant for all air velocities other than natural convection currents. The watts dissipated per unit area vary uniformly with the temperature excess for constant air velocities. However, it is not safe to assume from these experiments that such linear relationships continue to hold indefinitely as the watts dissipated increase.

Relations were also obtained between the watts dissipated per unit area and the air velocity for various constant temperature excesses, of 10, 20, 30, 50, and 70 deg. respectively. Such relations

are useful in determining the amounts of heat that can be liberated for definite temperature excesses and are shown in Fig. 5.

EFFECT OF ANGLE OF INCIDENCE OF AIR STREAM

All the foregoing results were obtained for perpendicular incidence or when the angle of incidence of the air stream was zero. From results that had been obtained previously on the cooling of a very small coil of wire ($\frac{1}{8}$ in. in diameter) when placed in an air current, it was seen that the amount of heat dissipated for a given temperature excess was different for different angles of incidence of the air stream. It therefore seemed worth while to make some tests to determine the way in which the temperature excess of the surface

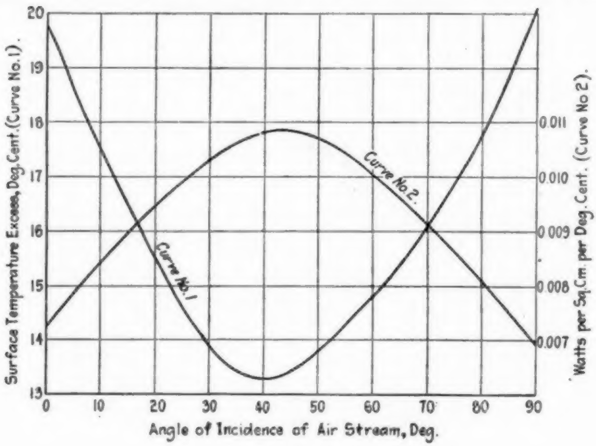

FIG. 6. EFFECT OF ANGLE OF INCIDENCE ON DISSIPATION OF HEAT

of the coil wrapper varied with the angle of incidence for a definite amount of heat dissipated per unit area and constant air velocity.

This was done for a dissipation of 0.145 watt per sq. cm. (0.938 watt per sq. in.) and an air velocity of 3267 ft. per min. Curve No. 1, Fig. 6, shows how the temperature excess changes under the above conditions as the angle of incidence of the air stream changes from zero, that is, perpendicularly, to 90 deg. or parallel to the coil. Curve No. 2 shows how the watts per square centimeter per degree centigrade change with the angle of incidence.

The curves are quite interesting in that they show the relative cooling effects of air at various angles of incidence. It is seen that the temperature excess for the particular air velocity of 3267 ft. per min. and a dissipation of 0.145 watt per sq. cm. at an angle of incidence of air stream of about 40 to 45 deg. is only 67 per cent of what it is for an angle of incidence of zero degree. Then, since

the watts dissipated vary directly with the temperature excess for a constant air velocity, it is seen that about 45 per cent more heat will be dissipated per degree under the above conditions of air velocity and heat supplied for an angle of incidence of about 42 deg. than for either perpendicular or parallel incidence. It is further seen that the least heat will be dissipated for 90 deg. incidence or when the coil is parallel to the air stream.

Values of the temperature excess were also obtained for 45 deg. and perpendicular incidence for various air velocities and a constant value of the heat dissipated of 0.130 watt per sq. cm. (0.840 watt per sq. in.). The curve in Fig. 7 represents the relative values of the temperature excess for perpendicular and 45 deg. incidence. It is seen that the temperature excess for a velocity of 4000 ft. per min. is 45 per cent greater for perpendicular incidence than for 45 deg.

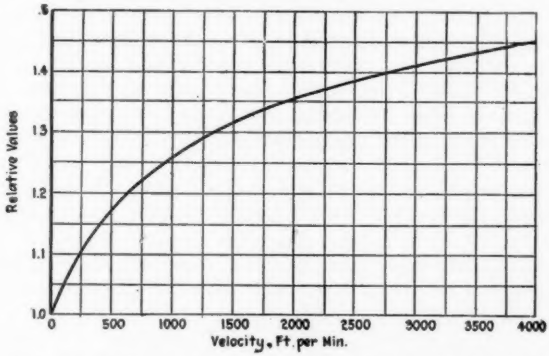

FIG. 7. CURVE SHOWING RELATIVE VALUES OF TEMPERATURE EXCESS

This is entirely in agreement with the results shown in Fig. 6. While these results have been obtained for a particular surface as well as for a special shaped coil,, it seems safe to assume that similar results should hold for all surfaces under the same conditions, the only difference being in the absolute order of magnitude and not relative order of magnitude.

Tests were also made for perpendicular incidence of the air stream for various positions of the coil about its axis. No noticeable difference was observed other than what might well be ascribed to experimental error. This is quite significant since it shows the factor of importance to be relative position of the axis of the coil in the air stream and not the relative position of the coil about its axis. Such a condition is quite likely to hold for all objects of relatively small cross-section completely within the unrestricted air stream.

In conclusion the writer takes pleasure in acknowledging his indebtedness to the Westinghouse Electric and Manufacturing Company in whose research laboratory the work was done, for furnishing the facilities for carrying out the experiments, and in particular to Mr. C. E. Nolan for his able assistance throughout the work.

DISCUSSION

L. R. INGERSOLL[1]: While somewhat striking at first sight the results of Mr. Taylor's investigation will be, by no means, surprising to one familiar with the main laws of heat transference. The effect would be exaggerated if the pipe were of very small diameter, for in this case, the addition of insulation would add appreciably to the radiating surface. Thus a current-carrying wire with insulation of not too low thermal conductivity, may run cooler than the same wire, if bare. From a practical standpoint, however, it seems to me that furnace pipes are so generally dirty and dusty that to leave off the customary asbestos paper covering in the expectation of saving heat would be a practice of doubtful wisdom.

L. B. MCMILLAN: This matter of differences in losses from bright and dull surfaces is a striking example of the effect of surface resistance. The author's conclusion that a thin layer of asbestos paper applied closely to a bright surface increases the loss of heat from the surface is, undoubtedly, correct and is in accordance with former tests of the same general nature. Calling attention to this fact will do a great deal of good in dispelling the popular notion that magical results can be obtained by the thinnest kind of a layer of asbestos. The thickness of asbestos applied in many cases is such that the effect is comparable with simply painting the name asbestos on the surface. Asbestos is a wonderful material and by making proper use of its high heat-resisting properties, very desirable results may be obtained; but the thickness and kind of material must be proportioned to suit the conditions.

However, the fact that a thin layer of asbestos increases rather than decreases the loss from a bright surface should not be misconstrued as indicating, that a bright surface requires no insulation. The increase in heat loss is due entirely to the change in the character of exposed surface. The resistance to heat flow on a bright surface is greater than that on a dull surface in the ratio of about 0.7 to 0.5. The addition of a thin layer of asbestos or other insulation, adds some resistance, but not enough to offset the decrease in surface resistance, due to the change from a bright to a dull, exposed surface. If sufficient insulation is used, it is possible to bring the loss to just as low a point in case the insulation is applied on a bright surface, as could be done by the same amount of insulation applied on a black or dull surface.

In the case of furnace pipes, the losses from the bright surfaces are so great that it would be wasteful to leave them bare. Therefore, if the bright surface is to be covered, what it would lose if exposed, is of little importance. The important thing is what one thickness of insulation will save when compared with another.

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[1]Professor of Physics, University of Wisconsin, Madison, Wis.

The case is a good deal like that of a man out in the cold clad in an undergarment. He would not be as much interested in whether one undergarment is warmer than another, as he would be in getting into really adequate clothing.

So in the case of the bright versus the dull surface, one loses less heat than the other, but both lose too much. Therefore, a warm overcoat is needed in each case. It should be noted that equation (1) and the computations in the following two paragraphs are based on the conductivity of asbestos paper, so closely wrapped as to exclude all air from between the layers. If plain asbestos paper were used it would never, in practice, be applied in that manner. A better type of material would be of cellular construction and actual test at the University of Illinois on pipes covered with 3 layers of air cell asbestos showed a saving just double that shown by the same material by the Author's calculation.

The author explains the increased heat loss from the papered surface on the basis of molecular area rather than on account of the brightness of the surface. Painting the bright surface with a smooth coat of paint (smoother even than galvanized iron) will increase the loss more than putting on asbestos paper does. Therefore, it would seem that molecular area had very little effect and that the difference was due to differences in radiation coefficients. The radiation even at the temperatures considered, amounts to almost one-half of the loss from dull surfaces and considerably less from bright surfaces, so that the change in radiating power is sufficient to account for the differences noted. It has been established by experiments that the radiation from a galvanized iron surface increases very materially, as the surface becomes tarnished. Tests reported in *Engineering* (London) October 11, 1917, showed that galvanized iron exposed to the weather for one year offers practically no more resistance to radiation than black iron. Even a few months exposure decreased the radiation resistance very greatly. This has no direct bearing on furnace pipes as they are not similarly exposed. However, even they do not maintain permanently their bright condition and the results of tests on bright surfaces cannot be considered as fairly representing the average losses from these surfaces.

E. R. HEDRICK[1]: There are two observations only that I want to make. One of them is that the laws that are presented here are for entirely different circumstances than are the laws which are made ordinarily for the dissipation of heat when a gas or other material is passed through a pipe; for in that case, a very important consideration, especially if there is a considerable drop in the temperature, is the contraction of the material as it passes down the pipe. Since the experiments here represented were conducted in a box of uniform size, one would not, therefore, expect any agreement whatever between the laws that are represented here and the laws

[1] Professor of Mathematics, University of Missouri, Columbia, Mo.

for transmission of heat in case the material is passing down a pipe, for that reason. The same quantity of gas, for instance, passing down a pipe may be exposed to a surface which is as much as one-fourth to one-tenth of the original surface to which it was first exposed when it was very hot, and certainly in the case of flue gases passing through a boiler tube.

The other remark that I have to make is that in an attempt to check with the result of the formula given by the author on page 419 I notice that the curves in Fig. 1 are not drawn with extreme accuracy. In fact, the figure shows a curve, No. 2[1], has a distinct curvature upwards as printed. As a matter of fact the figures which the author himself gives on the opposite page, when drawn accurately, show a distinct curve downward. This is of importance to anyone who is attempting to establish a law governing that phenomenon. I have not succeded in doing more than to check the result of that formula which the author gives as reasonably correct for the purposes which he has in mind. I do not believe, however, that the formula would hold with an arc of greater length, and I point out that the observations here carried on are for temperature differences of only 75 deg., which constitutes a very short arc for ordinary heat transmission purposes.

A. C. WILLARD and V. S. DAY[1] (written): This discussion deals only with the first part of Mr. Taylor's paper, and particularly with the "so-called" internal temperatures. In general, Mr. Taylor's results confirm the work in this field already completed at the University of Illinois, and reported in Bulletin[2] No. 117 of the Engineering Experiment Station as the "Emissivity of Heat from Various Surfaces," by V. S. Day. In fact, when the results of the two investigators are compared on the basis of the excess of surface temperatures of the cylinders above the surrounding room temperatures, a satisfactory agreement results. The importance of knowing the surface temperature of the cylinders tested, became so evident in the work done at the University of Illinois that it was decided to make the "internal temperature" of each cylinder the same as that of the metal surface itself by using dry, saturated steam. It appears that the internal temperatures used in determining the heat dissipated in Mr. Taylor's tests are based on mercury thermometer readings taken by a thermometer inserted through the sides of the cylinder tested, with the bulb apparently at the center of the cylinder. If this is the case, the thermometer bulb is also surrounded by the heating coil, and indicates an "internal air temperature" which is of more or less indefinite significance. Unfortunately, Mr. Taylor's paper shows no sectional or other views of his cylinders.

The above statement is made advisedly. Attempts to determine the "air temperature" with small thermocouples, No. 23 B. and S. gauge, in a 10 in. diameter tin leader pipe at the University of

[1] Research Assistant, Engineering Experiment Station, University of Illinois, Urbana, Ill.

[2] Reprinted in September, 1920, issue of Journal of A. S. H. & V. E.

Illinois, showed a drop of about 40 deg. fahr. from the air near the center of the pipe to the air near (approx. 0.01 in.) the inside surface of the pipe. Moreover, in the same tests the temperature of the metal of the pipe was found to be about 60 deg. fahr. lower than the air temperature near the center of the pipe. This was true for air flowing at 6 to 7 ft. per sec. with a maximum temperature near the center of the pipe of about 180 deg. fahr.

The variation in the "internal air temperature" across a pipe or cylinder, varies with a change in the rate of air flow and even in a closed cylinder there will be a marked difference between the temperature of the air near the center and the air in close contact with the cylinder walls.

It, therefore, appears that the only definite basis for estimating the amount of heat *dissipated by thin metal surfaces* which separate air or gas at high temperature is the difference between the surface itself and the temperature of the cooler surrounding air. In the above cases, the surface was so thin that the temperature drop through the metal is negligible as compared with the drop from the metal surface to the surrounding room temperatures. This was proved by actual test. Hence, if we take Mr. Taylor's values for the heat given off from a bare tin drum with the surface temperature 40 deg. cent. above room temperature from Curve 2 in Fig. 2, we find approximately 0.024 watts are dissipated per sq· cm. If reduced to a coefficient for practical use such as B.t.u. per sq. ft. per 1 deg. fahr. per hr. this becomes:

$$K. = \frac{.024 \times 929 \times 3.415}{40 \times 1.8} = 1.05 \text{ B.t.u.}$$

when the temperature differential is 72 deg. fahr. For a temperature differential considerably greater than this (135 deg. fahr.) Mr. Day reports a value of $K_2 = 1.28$ (p. 18 and 19 Bulletin No. 117, Engineering Experiment Station.)

Allowing 0.2 per cent increase or decrease per deg. variation in the value of K for a temperature difference from metal surface to surrounding air of 150 deg. fahr. we get for Mr. Taylor's emissivity value reduced to 150 deg. fahr. difference metal surface to air:

$$1.05 = K. - .002 \times (150 - 72) \times K.$$
$$K. = 1.24.$$

and for Mr. Day's emissivity value reduced to 150 deg. fahr. difference metal surface to air:

$$1.28 = K_2 - 0.002 \times (150 - 135) \times K_2.$$
$$K_2 = 1.32.$$

The value 0.002 is taken from tests by Prof. J. R. Allen to show the variation in the transmission of heat from a radiator for varying differences in temperature between heating and cooling media.

It will, therefore, be apparent that Mr. Taylor's values of the coefficient of emissivity when surface temperatures are used as a basis are only 5 to 6 per cent lower than Mr. Day's values for bright tin cylinders.

P. NICHOLLS: I would just like to add a word for Dr. Taylor, who had not received the results of the Illinois experiments and was not aware that they were carrying them out to such a great extent when he wrote his paper, consequently, the Illinois results have gone a great deal further than Dr. Taylor.

The differences, of course, are clearly explained, for Dr. Taylor took his temperatures in the middle of the apparatus, and was merely getting the total drop from the inside temperature of the material. He brings out the point, that the various items must be separated into definitely-agreed-upon losses.

J. D. HOFFMAN: I was impressed with the similarity of the results obtained by Mr. Taylor and those obtained and reported last summer by Prof. Willard, of the University of Illinois. In his paper Prof. Willard proved that some of our most time-honored practices were wholly wrong. Now Mr. Taylor confirms these conclusions. I value Mr. Taylor's paper as a clinching argument. I was also impressed with the value of Fig. 5, of the paper in that it confirms much of the work done by Mr. Soule, of the American Radiator Company, on blast heating, where the conductivity and the heat transmission from the steam within the coils to the air passing over the coils seemed to follow about the same law as shown in these results.

THE AUTHOR: If Mr. Ingersoll will observe the data in Tables 1 and 2, it will readily be seen that a dust-covered bare pipe still loses about 25 per cent less heat than the same pipe covered with the usual layer of asbestos paper when dust coated. Consequently there is no doubt but that so long as one can keep the pipes free from rust, there is no advantage to be gained by putting on a thin layer of asbestos in the usual manner. On the contrary it is a decided disadvantage.

As is indicated by Mr. Ingersoll, it is a well-known fact that of two cables of the same carrying capacity but having different thicknesses of insulation, the one with the thinner insulation will have the higher conductor temperature under similar conditions. Furthermore, each will be cooler than the bare conductor. This particular fact cannot be interpreted to apply to all cases of insulated bodies. If one knows the constants of the insulation and of the surface one can calculate what thickness of insulation would give a minimum temperature of the conductor or pipe to be insulated. In the case of steam pipes the so-called coefficient of emission is too high to give such a result as is indicated above for cables. In other words the diameter of the pipe would have to be very small indeed to have a thickness of insulation which would give a minimum temperature

of the pipe. The proper radius of the pipe including insulation can be shown to be $r = \frac{E}{k}$ for a minimum temperature where k is the conductivity of the material and E the coefficient of dissipation of the surface of the insulation. So that for all steam pipes in use the radius is always greater than this radius indicated above and consequently the application of insulation will always conserve heat.

When considering the influence of a layer of asbestos on a hot-air pipe, one readily sees that the asbestos layer does not increase the effective radius of the pipe, but it does increase very materially the effective surface from which heat can be dissipated both by radiation and convection. This is due to the fact that a very uneven surface as far as molecular dimensions and motions are concerned is substituted for a very smooth surface and one which has a low radiating power.

The author would not have Mr. McMillan think it was his intention to advocate that, in general, a bright surface needs no insulation. However, scientific facts are usually interpreted to indicate the most satisfactory and economical procedure. Since it is the popular belief, not only among the non-scientific people but even among those of scientific training, that the usual method of covering hot air pipes with a thin layer of asbestos paper is a great economy, it is the intention of the author to call attention to the facts in the case as obtained from trustworthy tests and point out that the present methods of insulating hot-air pipes is a useless expense, instead of an economy.

According to Mr. McMillan's statement the losses from a bright hot-air pipe are so great that it would be wasteful to have them bare. The results shown here and those obtained by Messrs. Willard and Day are by no means in accordance with such a statement. From a consideration of the results as shown herein, it is quite doubtful whether it is economy to apply sufficient thickness of insulation to reduce the losses to say 75 per cent of that from a bare pipe. This would require about seven layers of thin-sheet asbestos applied loosely or about three layers of the usual ¼-in. air cell. The expense and trouble to do so is considerable and it is very questionable whether it is at all economical.

Mr. McMillan is very much in error when he says that painting a bright surface with a smooth coat of paint increases the losses even more than a layer of asbestos applied in the customary manner By reference to Table 2 it is readily seen that experiments show just the opposite to be the case. An asbestos layer on tin increases the losses 37 per cent, while a coat of aluminum paint increases the losses but 13 per cent. Mr. McMillan certainly did not interpret the data given in this paper correctly if he obtained such an idea from the results contained therein. As is pointed out in the main text of the paper, molecular area does have a very important part in determining the losses from the surface By introducing a rough

surface such as asbestos instead of a bright surface, the effective molecular area is very considerably increased. This furnishes more points and surface from which radiation can take place and also with which the molecules can come into intimate contact. Consequently more heat must be carried away.

That the losses due to radiation alone at the temperature of steam pipes are about one-half the total losses is quite doubtful. By using the accepted value of the coefficient of radiation for a black body at such temperatures, it is easily shown from Stefan's Law that not nearly one-half the amount of heat should be expected to be lost by radiation. Those experiments which indicate such to be the case were not performed in a sufficiently good vacuum to be rid of convection losses. In fact the pressure was still sufficient to permit of very considerable losses by convection on account of the large magnitude of the mean free path of the molecules at such pressures. The fact that the so-called radiation resistance of galvanized iron decreases as the surface becomes tarnished confirms the statement that molecular area has considerable to do with the heat lost. The tarnishing of the surface results chiefly in increasing the molecular area by the forming of the oxide.

As indicated above, while these tests show the uselessness of covering hot air furnace pipes with the usual thin-sheet asbestos, the same conclusions must not be drawn with respect to steam pipes. In the latter case we are dealing with very good radiators, having uneven surfaces and thus large molecular area, and where it has been the practice to use sufficient insulation to cut down very noticeably the heat losses.

Contrary to Mr. Hedrick's view, there seems to the writer to be no reason why the laws governing the loss of heat from the outer surface of a covered or uncovered hot-air pipe should be any different for a pipe in which the air was moving and when the air was stationary. To be sure the average value of the internal temperature will have a different significance. The manner in which the surface obtains its heat from within, from still air, moving air, steam or water will have no effect upon the laws governing the loss of heat from the outer surface. These factors will only determine the relative temperature of the outside with respect to the surroundings. The formula on page 419 was found to fit the curves such as 1 and 2 in Fig. 1 very nicely for several cases. To be sure if the temperature increased sufficiently high a third term involving the fourth power of the temperature excess was useful in getting a more accurate agreement between the equation and the observed curve. This extra term is useful in taking account of the extra heat lost at the higher temperatures due to radiation. At the ordinary temperatures found in hot-air pipes and in particular those found in the outer surfaces of such, the heat lost by radiation is quite small ideed.

Curve 1 does and should have a curvature upward. It is plotted from the results in column 2, Table 1 by dividing each by its corres-

ponding temperature. Prof. Hedrick is not correct in his statement that the curve bends downward at all. He must have used his coordinates differently to get that result. It should have a slight upward curvature, especially since the radiation factor would become more and more important with increasing temperature and instead of watts per unit area per degree excess varying as the first power of the temperature for higher temperatures, it must vary with a higher power of the temperature.

In their discussion, Messrs. Willard and Day state that since the internal temperature of the vessels was determined by means of a mercury thermometer inserted through the sides of the cylinders, this internal air temperature has a more or less indefinite significance. Since the heater was of cylindrical form and of such dimensions, as is pointed out in the paper, to permit its being readily slipped into the vessels without making electrical contact with their sides, the entire inner part within the heater would attain a very definite constant temperature for a given input. The only drop in temperature within the vessel would be from the heater to the walls, ends and sides, of the vessel. This distance was of the order of $\frac{3}{32}$ in. and consequently the drop from the heater to the vessel walls would attain a definite value for each input. Thus the temperature indicated by the thermometer would represent the temperature of the entire space within the heater, which was by far the greater part of the inclosed space within the vessel. There is little question but that such an arrangement would give an internal temperature as determined much more definite than could possibly be obtained by allowing dry saturated steam to flow into the vessel and be condensed on its walls. This latter method is certain to give considerable temperature drop from the center of the vessel to its walls and would not give a large volume of a definite constant temperature such as is obtained by the author's arrangement. Furthermore, it is by no means safe to assume that the walls of the vessel, when dry saturated steam is passed into it and condensed on its walls, are at the same temperature as that of the enclosure. The steam if saturated will become cooled as it advances towards the walls and a part will be condensed before reaching the walls.

Experiments show that an object which has a surface temperature excess above surrounding air temperature of 180 deg. fahr. in still air will have less than 90 deg. fahr. temperature excess when placed in an air stream of the same temperature and having a velocity of 500 ft. per min. Thus the temperature of a surface is greatly dependent upon the velocity and temperature of the air stream passing over it. In a similar manner there will be a considerable drop in temperature between the center of a pipe and the pipe itself even at low velocities. Even though steam may be used as pointed out above there will be a drop in temperature between the center of the tube and the walls due to condensation or cooling of the steam as it approaches the walls of the vessel. To the author, the internal

temperature of the vessels as measured by the thermometer would have a very much more definite value than it would have in the arrangement suggested by Messrs. Willard and Day.

It is quite comforting to note that the so-called coefficient of emission as obtained from the author's results and those obtained by Mr. Day has practically the same value. This is particularly true when one considers that such a coefficient of emissivity depends upon so many different factors—the nature of the surface, temperature of surface and surrounding objects, etc., and is dependent upon the loss of heat by radiation and free convection as well as the relative distribution of the loss between these two methods of transfer of heat.

No. 568

SHIP VENTILATION

By F. R. Still, Detroit, Mich.

Member

THERE has never been, and there is yet no definite or standardized method of ventilating ships of any class, type or size, except perhaps battle ships, and even for them, the old standards are to be revised as a result of the battle off Jutland, between the German and British fleets. The use of poisonous gas by the Germans showed the urgent necessity for making some very important changes in future designs, which will probably be incorporated in the plans and specifications for all new warships built by the United States.

There are a great many types of ships to consider, for the oceans, lakes and rivers; for passengers and for freight; for cold and for tropical climates; for carrying bulk or package freight; for perishable or non-perishable freight; for carrying cattle, horses, sheep or hogs; whether designed for war or commerce; for daylight trips or night trips, and for numberless other purposes. They may be classified somewhat in accordance with Table 1. While this by no means covers all the uses for which ships may be catalogued, it covers the more important lines and is a sufficient outline for the purpose of this paper.

Ships of all classes, excepting perhaps coastal vessels, are subjected to a great variety of climates within very short periods, on most of the lanes of sea-travel. Hence those quarters which are to be occupied by human beings or animals, also for certain classes of perishable freight, such as meat, fruit, vegetables or anything that can be easily decomposed, either because of heat or moisture, should be well ventilated by a positive method, which is not dependent upon the motion of the ship or the vagaries of the wind; upon whether a tropical sun is shining or the cold blasts of the artic are blowing down under a leaden sky. It naturally follows, that in order to make such a system *thoroughly effective*, it must be combined with a means for heating and for cooling the circulated air, which latter must be automatically controlled as to temperature as the require-

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TABLE 1. CLASSIFICATION OF SHIPS WITH REGARD TO VENTILATION

Class	*Types*	*Methods*
Naval Vessels	Battle Ships Cruisers Destroyers Transports Colliers Submarines	Ventilation very extensive and thorough. Designed by the Navy Department and installed according to rigid specifications which are obtainable from the Bureau of Construction and Repair, U. S. Navy Department Washington, D. C.
Regular Liners	Passenger Ships only Passenger and Freight Package Freighters Bulk Freighters Refrigerated Ships	Usually fairly well ventilated. Adequacy depends largely upon the designer, who exercises his own judgment as to the method and extent to be employed, resulting in a great variety of installations and corresponding results.
General Freighters	Package Freighters Bulk Freighters Cattle Ships Tankers Sailing and Motor Ships	Seldom any provision for ventilation, except under compulsion by law, or to a very limited extent in quarters like the boiler and engine rooms, the galley, toilets and forecastle.
Coastal Vessels	Passenger Liners Lake and River Steamers Package Freighters Bulk Freighters Ferry Boats	Practically no provision for ventilation except as noted in preceding class. Dependent almost entirely upon cowls, wind-sails, port-hole scoops and the wind, for such ventilation as is obtained.

ments necessitate, to give the proper degree of comfort at all times. Such a system has never yet been installed on any ship on the high seas, so far as known. Provision has been made for heating by air circulation and it has been made for cooling by that means, but no really well-thought-out plan has ever been attempted for combining the two for thoroughly ventilating a ship at all times by means of air properly attempered and automatically regulated to such climatic and weather conditions as may be encountered on the various seas and in the various parts of the world. It would be a difficult and expensive undertaking. There is so little room available and so many obstacles to prevent running the conduits, besides the necessity for limiting the weight of the ventilating apparatus to the minimum, and the possibility of the apparatus getting out of order, that most naval architects, marine engineers and ship builders, hesitate to even recommend it, much less undertake to install such an elaborate system, regardless of how well they may be convinced of its desirability.

This covers the general status of ship ventilation, as at present practiced and what should and may be the aim of designers for the ventilation of ships in the future. Next in order is to consider more in detail what is the practice of typical ships of the various classes:

NAVAL VESSELS

Naval vessels of the various types may as well be passed over, as this is a highly specialized line that seldom, if ever, comes under the consideration of the architect or engineer in commercial practice. Past standards will soon be, if they have not already been revised, and this is a further reason for giving no space to that class at this time.

REGULAR LINERS

Passenger Ships: The mammoth, high-speed liners, which are designed primarily for carrying only passengers, mail, express packages and a limited amount of freight, are usually provided with means for obtaining an adequate supply of fresh air throughout all parts of the ship, wherever needed, especially when the ship is under way; as there are seldom many passengers aboard when the ship is in port for any duration, the limited amount of forced ventilation provided is usually adequate. When one of these ships stops, especially in a warm climate, if there is no wind blowing the interior of the ship soon becomes unbearable, not only on account of the heat but due to the bad conditions of the air, as most of the ventilation is provided for by means of cowls, located on the orlop, promenade and hurricane decks, and their effectiveness is entirely dependent upon the air or the speed of the ship. At times, they prove very ineffective even when the ship is under way, especially with a following wind over the stern at a velocity about the same as the speed of the ship. Sometimes, as a means of giving some relief under such conditions, wind-sails are put up to direct more air into the cowls. These wind-sails are made of canvas, of large area and are spread out in conical form, being held in position by lashing to convenient shrouds, stays, halyards or stanchions. They are more frequently used on schooners than on steamships but are not uncommon on the latter when necessity occasions them.

Such forced ventilating plants as are provided, are usually located on the promenade and hurricane decks. Most of them consist of a fan, driven by an enclosed, water-proof, direct-connected, electric motor. The intake to the fan is housed over in such a manner that the spray from any seas which may come aboard, will not be drawn into the fan and thereby get into conduits. Whether the air supply goes to compartments amply heated or over warm, which thereby will be comfortable with only unheated air, determines whether or not there is a bank of steam coils in combination with the fan. Fans for ventilating the dining saloon, smoking room, lounge, music room and the main passageways, usually have a bank of steam coils to temper the air to be delivered to those compartments. Some of these outfits are arranged for the fan to draw the air over the coils and others to force or blow the air in contact with the coils. The latter is the more efficient method, but the former makes a more compact unit, for which reason it is more generally adopted.

In addition to the forced systems of ventilation above referred to, there are generally installed many exhaust fans, all over the ship, some being above the main deck and some below decks, wherever most convenient to place them and where easiest to run the conduits to and from the fan. Greater dependence is really placed on the exhaust fans for the purpose of maintaining purity of the atmosphere within the ship, than is placed upon the plenum systems, in the ventilation of most ships, judging from the greater number of exhaust fans used. The average naval architect or marine engineer evidently thinks that if a partial vacuum is maintained within the

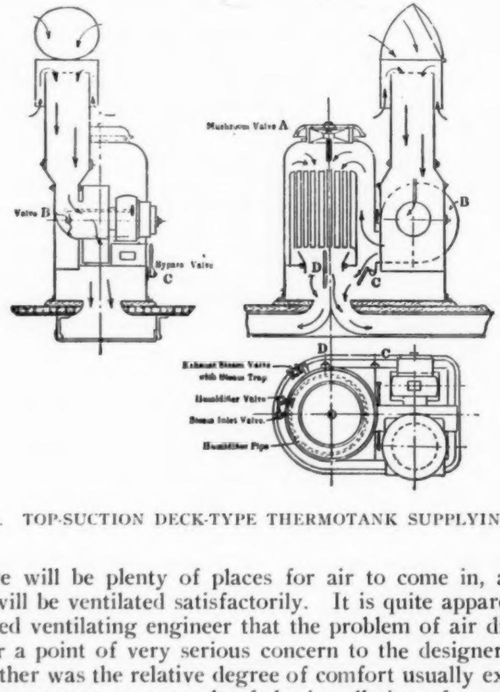

FIG. 1. TOP-SUCTION DECK-TYPE THERMOTANK SUPPLYING AIR

ship, there will be plenty of places for air to come in, and hence the ship will be ventilated satisfactorily. It is quite apparent to any experienced ventilating engineer that the problem of air distribution was never a point of very serious concern to the designers of most ships; neither was the relative degree of comfort usually experienced from air movement, as a result of the installation of a well-distributed plenum system, a matter which received very much consideration, when the selection of one of the two methods of ventilation was decided upon.

Air movement (without draft) is a greater factor in the comfort a human being derives from a ventilating system (excepting perhaps odors) than almost anything else. It is practically *impossible to create a noticeable air movement by exhausting the air from a room;* whereas, it is quite easily and inexpensively accomplished by a plenum system in most rooms. Furthermore an exhaust system,

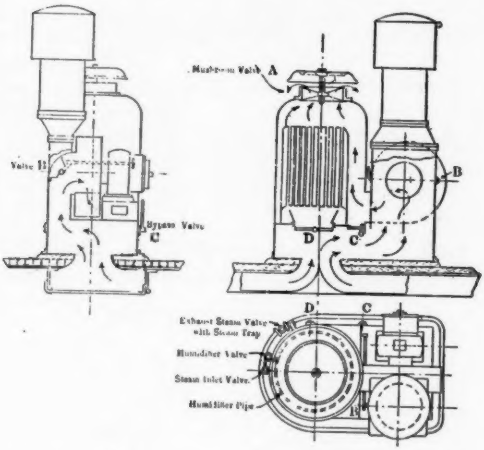

FIG. 2. TOP-SUCTION DECK-TYPE THERMOTANK EXHAUSTING AIR

invariably short-circuits an air current across a limited area in a room, without materially affecting the condition of the air beyond the area referred to; whereas it is usually possible to refresh the air in the remotest corners of a room with a properly designed plenum system. These are two very important points to remember in de-

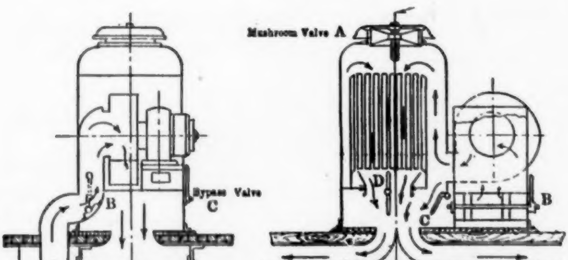

FIG. 3. BOTTOM-SUCTION DECK-TYPE THERMOTANK SUPPLYING AIR

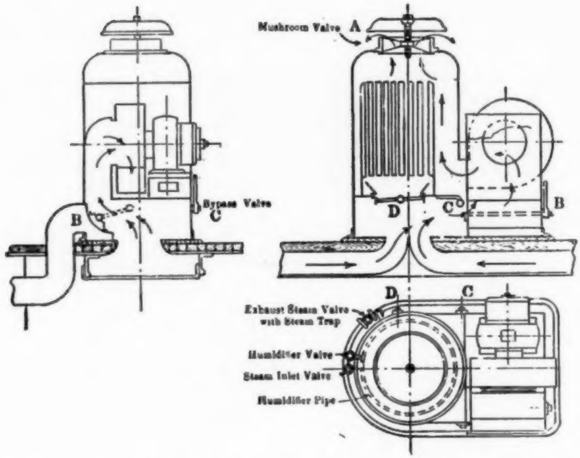

FIG. 4. BOTTOM-SUCTION DECK-TYPE THERMOTANK EXHAUSTING AIR

signing any ventilating plant for any purpose whatsoever; viz.: *air distribution* and *air movement*. At similar temperatures, the relative comfort obtainable from a plenum system as compared to the

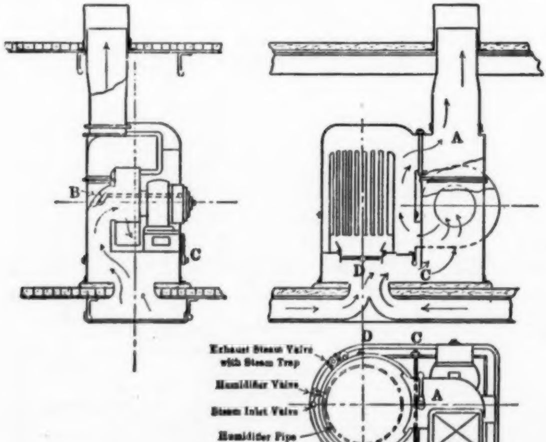

FIG. 5 'TWEEN-DECK-TYPE THERMOTANK EXHAUSTING AIR

discomfort usually resulting from the circulation of the same volume and temperature of air with an exhaust system, is hardly believable, until one has experienced the difference under similar oppressive conditions.

Sometimes steam jets are used to inject moisture into the air supplied by forced ventilating systems. This gives an added degree of comfort in very cold weather by increasing the relative humidity. Cold water sprays or cold water circulated through the coils is sometimes used for cooling the air in hot weather. Both are requirements

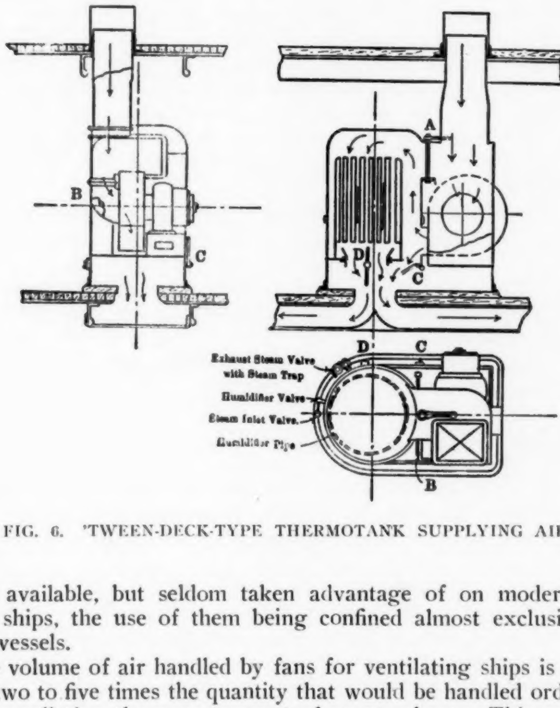

FIG. 6. 'TWEEN-DECK-TYPE THERMOTANK SUPPLYING AIR

easily available, but seldom taken advantage of on modern merchant ships, the use of them being confined almost exclusively to naval vessels.

The volume of air handled by fans for ventilating ships is usually from two to five times the quantity that would be handled ordinarily, when ventilating the same amount of space ashore. This provision is probably the outgrowth of experience rather than of fundamental engineering data. With the exception of the dining saloon, the lounge and the smoking room, which are usually provided with air volumes approximating land standards, all other large compartments have from two to three times those standards, while very small compartments, like state rooms or closets, have a supply of from three to five times. This may be a wise provision, considering the variety of climatic conditions encountered, but if more study were given to *air distribution* and *air movement*, there would hardly be any more reason for it aboard ship than ashore.

Fans for ventilation aboard ship, can be run at higher speeds and the air driven at higher velocities than for a similar purpose in public buildings, because absolute noiselessness is not so essential. While a fan can by no means be permitted to pound, whistle or rumble without causing complaint on a ship, there are so many other noises that the rush of air or the whir it makes as it passes through the fan and the ducts is not objectionable even at velocities 50 per cent higher than is the practice in buildings. This enables the designer to make the ducts comparatively small, which is so essential in the limited space available. It therefore remains with him simply a consideration of the space available and the power he cares to expend in moving the air, at any velocity less than say 3000 ft. per minute, as to whatever size he will make the conduits to convey the volume of air required. The usual practice is to adopt a conduit velocity between 2000 and 2400 ft. per minute, with expanding terminals on the branches, leading to the outlet from the main trunk duct, of an area sufficient to reduce the velocity down to 900 or 1200 ft. per minute.

Great disregard of frictional resistance, by the multiplicity of abrupt turns and elbows in the ducts, is noticeable on all ship work. Sheet metal workers seem to take pride in an exhibition of their handicraft by making an air duct fit neatly around every deck-beam, brace or stanchion that intercepts its course, instead of seeking out a common level where the least number of turns, offsets and elbows will be required; this needlessly increases the speed the fan should have to run, with a corresponding increase in the power required to drive it, to obtain desired results.

As it is seldom possible that a duct beneath a deck can be much deeper than 10 or 12 in. and as this frequently results in a width so utterly out of proportion as to be certain of inefficient distribution, it is then better to split the system up between two smaller units, locating each of them at points nearer their ultimate point of discharge.

Another noticeable thing is the practice of carrying most of the ducts long distances horizontally, whereas the provision of three or four good sized vertical fresh air shafts, from the hurricane deck down into the lower depths of the ship, would permit locating the fans to much better advantage for the purposes intended. By extending vertical discharge ducts upward, the general arrangement could be made just as effective, more sightly, take up less valuable deck space, work more efficiently and the fans would be where they could have better attention by the engineering staff, than they receive where most of them are now located.

Fan housings for ship-work should be made of much heavier material than is customarily provided. They are subjected to very rough usage aboard ships. All sorts of things bump into them and unless built heavy enough to resist they soon become very unsightly, if not put out of commission entirely. Not only this, but the steel oxidizes rapidly under the influence of the moisture and

salt water spray, no matter how well protected by painting. The plate should be no less than 1/8 in. and preferably 3/16 or 1/4 in., especially on large sizes. The angle-iron braces and castings should be correspondingly heavy. The fan wheel should always be mounted on a tapered shaft so it can be easily removed for repairs, even if the shaft becomes badly rusted. Every precaution should be taken against mechanical weaknesses and liability to get out of adjustment during long and continuous running periods. Spare parts for the motors should always be included and a very good plan, when laying out a ventilating plant for a ship is, to endeavor to divide it up into as many units of the same size and power as possible, so that by having one or two extra spare parts for anything on one unit, owing to their interchangeability, quick replacements can be made at any time, without having to await arrival in port to make repair before the unit can again be put into commission.

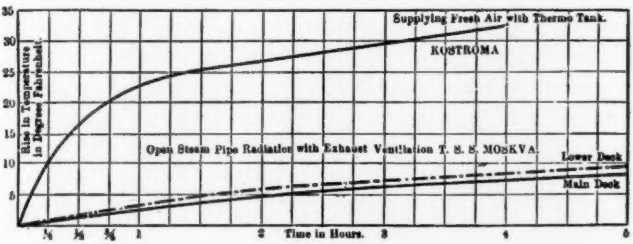

FIG. 7. THERMOTANK HEATING COMPARED WITH OPEN STEAM PIPES

This covers the big liners so far as concerns the general requirements for passenger ship ventilation. It is by far the most extensive and exacting of any class except naval vessels. What is applicable to the passenger liner is applicable to any other passenger vessels other than river steamers and ferry boats. The only difference is that the others are on a less extensive scale. In other words, the same rules apply to a simpler problem on smaller passenger boats and mixed passenger and freight boats.

Refrigerated Ships: Ships designed for carrying meats, fresh fruits and vegetables are usually provided with a refrigerating plant, the hull of the ship being throughly insulated. In some of the ships built in the last few years, refrigerated air is circulated by means of fans, as it has been found that the cargo is kept in better condition than without air circulation. The method usually adopted is to recirculate the air by removing it from the top of a compartment into one duct and blowing it in at the bottom of the compartment through another. The air drawn off at the top on the way back to the fan, passes over a bank of refrigerating coils, which cools it to a lower temperature and thereby condenses any moisture the air may contain

down to the dew point at the temperature produced by the coils. Then the air is blown back into the compartments again to repeat the operation over and over again.

The cause of fermentation or decay in any matter is moisture in the right amount and at a favorable temperature for the propagation of the active elements of its composition. Lowering the temperature retards the activity of these elements but as soon as the temperature is allowed to rise again the process of fermentation and decay begins action at once and always with greater vigor, resulting

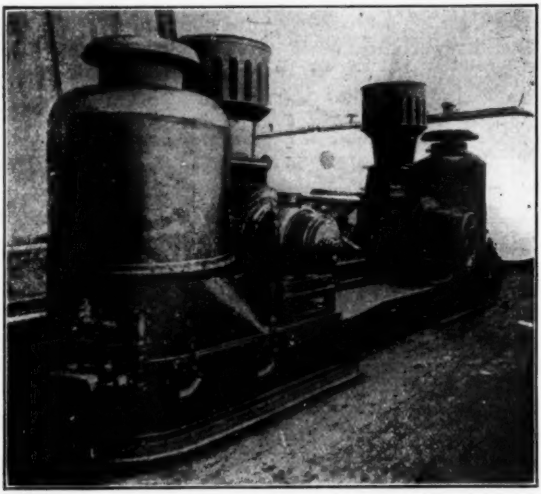

FIG. 8. TOP-SUCTION DECK-TYPE THERMOTANK FOR FIRST CLASS ACCOMMODATION ON LUSITANIA

in quicker decomposition, especially as the age of the product increases. By circulating refrigerated air in the cargo, a certain amount of evaporation of the moisture present is constantly taking place, thereby not only still further retarding the activity of the elements which cause fermentation and decay, but at the same time lessening to a very considerable degree the rapidity with which decomposition begins to take place when the temperature rises, as it is bound to do when unloading and transferring the cargo from the ship to warehouses or to the markets.

A ship of about 4000 net tons would ordinarily be furnished with two fans of the Sirocco type with wheels 24 to 30 in. diameter, requiring about a 5 h. p. motor to drive each of them.

Cattle Ships: It was very uncommon for any attempt to be made to ventilate cattle-ships until the World War broke out. Entirely

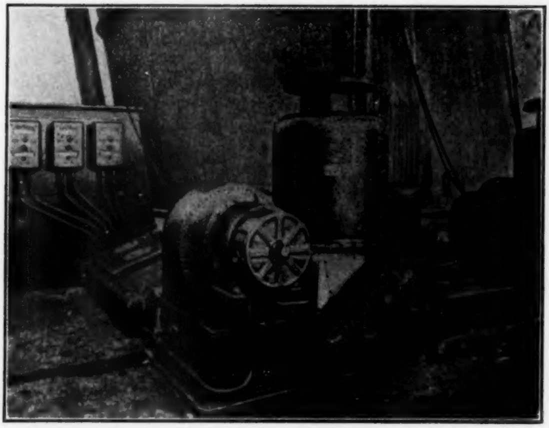

FIG. 9. BOTTOM-SUCTION DECK-TYPE THERMOTANK FOR FIRST CLASS ACCOMMODATION ON LUSITANIA

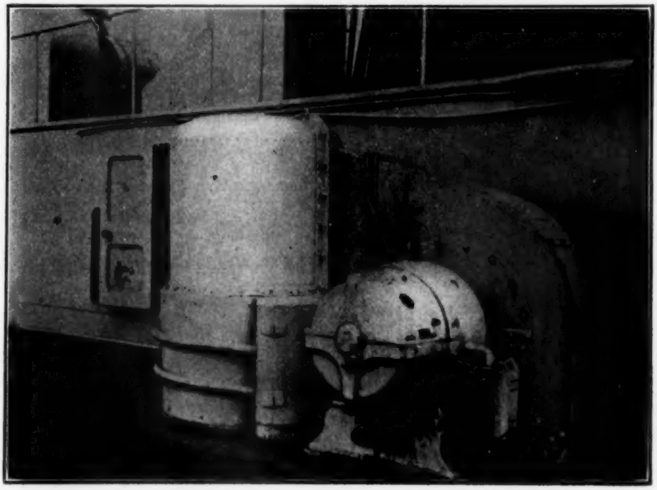

FIG. 10. DECK-TYPE THERMOTANK INSTALLATION, NOT INTERCHANGEABLE

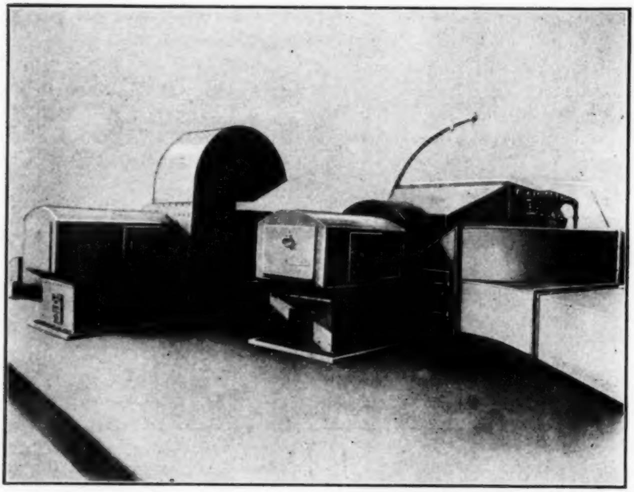

FIG. 11. DECK-TYPE VENTILATING EQUIPMENTS FOR SUPPLYING AND EXHAUSTING AIR ON STEAMSHIPS ST. LOUIS AND ST. PAUL

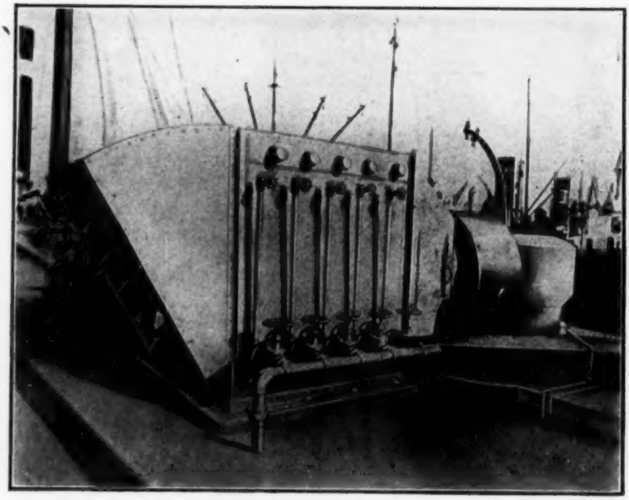

FIG. 12. INLET END OF SUPPLY VENTILATING EQUIPMENT SHOWN IN FIG. 11

aside from any human considerations, but viewed solely from an economic standpoint, as well as for sanitary reasons, ships intended for this kind of trade should be well ventilated, and it is now so demanded by the U. S. Government. Without ample ventilation, the loss of animals while crossing the ocean is something appalling. Packed away, as they are down in the depths of the ship, should an animal die while in transit, it usually has to be left there until port is reached. The conditions below deck become something awful, particularly in warm weather. It is more amazing that any of the

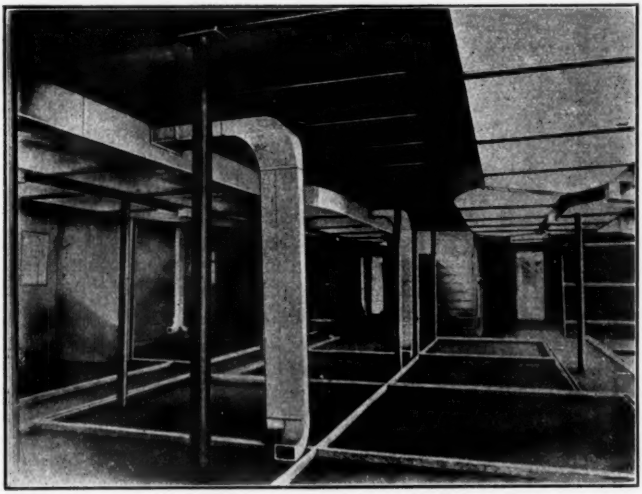

FIG. 13. CONSTRUCTION VIEW SHOWING INSTALLATION OF DUCT WORK FOR VENTILATING STEAMSHIPS ST. LOUIS AND ST. PAUL

animals survive the passage, than that only the few of them die as do succumb.

Most of the ships employed in this trade are comparatively small, usually not exceeding 2000 to 3000 tons. Such a ship will frequently carry upwards of 1000 or more cattle or horses, and correspondingly more of smaller animals. Two fans should be provided having a capacity of from 12,000 to 15,000 cu. ft. per min. each, with about 7½ h. p. motors or engines to drive them. Such fans of the Sirocco type would have wheels about 36 in. diameter.

The usual method of installing the ducts is to suspend two trunk lines of ducts from the main deck, just outside the hatches, on either side of the ship, with branch lines carried athwartship and downward, at suitable intervals, to give the required distribution of air. Some installations depend upon cowls for the inlet of the fresh air and

employ exhaust fans to remove the air from the ship, but this is by no means so effective as to force in fresh air with fans and provide suitable stationary ventilators to allow the vitiated air to escape.

On ships smaller than 2000 tons, one fan with one trunk line is sometimes employed with fairly satisfactory results; but as a rule two are better, regardless of size; while the cost may be a little more with two units, the arrangement can be worked out so much better and the results are so far superior to those obtainable with one unit, as to recommend it in preference for almost any case.

General Freighters: No provision for ventilation is provided on any other types of freighters than the foregoing beyond that obtained by cowls, port-holes, windows, skylights, dead-lights, port-hole scoops, wind-sails and companion-ways, as it is hardly necessary. The crews are seldom large and few of them are below deck at any one time. Most of the accommodations are in deck houses, having ample natural ventilation by means of port holes, skylights or windows which can be opened or closed, as may be desired.

On mixed freight and passenger steamers, very little mechanical ventilation is required, as most of the passenger accommodations are above the main deck with ample outside exposure. Interior quarters may need some special consideration, in which case the same methods are pursued as have already been covered by the description of the methods employed on passenger liners.

Lake and River Steamers: On the Great Lakes, the Hudson River and some of the Sound Steamers running between New York and Boston, will be found a system employed, peculiar to those particular types of side-wheel steamers, which were all designed by Mr. Frank E. Kirby, the celebrated naval architect. The method is known as the McCreery system. It consists mainly of a fan or fans, capable of producing a high velocity of air through the ducts and discharging out of orifices from 2 to 4 in. diameter, fitted either with adjustable elbows or having a peculiarly designed shutter-device, with adjustable louvers to deflect the air at any desired angle, which in turn are trunnioned into a collar that can be turned around so as to throw the air straight out, to the right or left, or upward or downward as may be found most desirable or the air can be shut off entirely. The air ducts run everywhere, concealed behind the panelled woodwork, with outlets appearing in almost every conceivable place where a person may be situated inside the cabins or state rooms. From these little openings always issues a gentle breeze, in such close proximity that it is at once noticeable, yet seldom objectionable; if it is, it can be readily deflected to some other direction. No attempt is made with this system to ventilate ships according to any definite standards; it is simply a means to provide plenty of fresh air for usual requirements, and to introduce it right where most of the passengers will obtain the direct benefit from it and still retain within the control of each individual the privilege of having the air blow directly onto him or past him, as may afford him the greatest comfort. It has proven extremely

satisfactory and due to repeated installations, under the able direction of the designer of the ships on which it has been used, very marked improvements have been made year after year. Great ingenuity has been shown in recent installations by finding new places to introduce the air inconspicuously, so as to be in keeping with the rich decorations employed on these ships.

It is beyond a doubt the most satisfactory method of ventilating this particular type of ship and could well be employed more extensively, with equally satisfactory results on other types, particularly on ships sailing in the tropics.

As stated at the beginning, there are no definite standards for ventilating ships of any class. Beyond a doubt, future competition between large transportation companies will eventually lead to more careful study of the comfort of passengers and hardly anything will have a more direct effect upon their appreciative sensibilities than better heating and ventilating methods than are now commonly employed. It is a difficult and bothersome problem for the naval architect or marine engineer to have to deal with and it is expensive to install in a thoroughly complete manner; but it is coming, because the people will demand it as soon as they become aware of the added comfort that will accrue and learn that it is obtainable if insisted upon.

No. 569

THE SIGNIFICANCE OF ODORLESS CONCENTRATION OF OZONE IN VENTILATION

By E. S. Hallett, St. Louis, Mo.

Member

THE paper read before the last meeting of the American Society of Heating and Ventilating Engineers has brought a great number of inquiries which can not be properly answered in individual letters and it is thought best to present this paper as a means of giving assurance to those who are desirous of using ozone in ventilation.

The new interest in ozone is a surprise to some and is due to a re-study of the whole situation. Many of the statements made as a result of early investigations were proven conclusively to be erroneous. It has been proven beyond question that Jordan and Carlson's statement that ozone only masked odors was untrue. It is evident that the useful applications of this highly beneficial resource of nature has been delayed by the activities of two classes of charlatans: the vendors of portable apparatus who had no knowledge of means of distribution nor of proper concentration, whose extravagant statements could be realized only occasionally and accidentally and the pseudo-scientists who investigated ozone by reference to the "literature" and by attempts to make the experiments fit their conclusions.

In recent years, however, many reliable investigators have done really constructive work on ozone. Olson and Ulrich cleared up much doubt. In 1913 and 1914, Dr. M. W. Franklin read papers in this Society that, in the opinion of the writer, argued strongly for ozone in ventilation. If laboratory tests and scientific proofs could have brought ozone into use Dr. Franklin's work should have done it. but the practical engineer and his more practical client have not the time or patience to pass on a controversy of theoretical scientists and so the question stood in abeyance.

It seemed to the writer that the actual operation of ozone in a full size school with a modern blast fan ventilating system under normal conditions throughout should be conducted; that medical supervision

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should be made by the official medical staff; that the teachers and pupils should not be "fed up" on any theory but that the response should come spontaneously; that great care should be taken to avoid the effect of the "psychology" in the determinations; that means should be provided for the control of the ozone concentration. All these things were done in the St. Louis schools and are in operation at this moment. The results were briefly outlined in my previous paper.

It developed early in the experiments that the chemical methods of determination of ozone could not be utilized for ventilation purposes for two reasons: first, the apparatus must be used in all kinds of places and under all conditions in which boilers and fans are used, and chemical tests are not available; second, that odors and such gases as vitiate air are in such low concentrations that no chemical means exist for their detection and likewise the proper concentration of ozone for ventilation is so low as to be measured with the accuracy of "rough approximation" only.

Ozone must now be considered from a new or different angle. For ventilation purposes it must be odorless. Some means of stressing the emphasis on the odorless concentration must be found. The term odorless ozone may subject one to criticism but this restriction is necessary. Ozone must be used with the same limitations as heat, except that the heat control must be confined to relatively narrower limits than ozone. We have warming heat and burning heat, yet no one discusses the heat of a blast furnace in connection with the warming of a school room—this, to show the absurdity of dragging into the discussion high artificial concentration of ozone.

Ozone in ventilation is not a stimulant. After two years of experience with it in the St. Louis Schools and in the observation of it in the writer's home and in large offices and stores there is no indication of stimulation of the occupants. Stimulants are followed by a reaction or corresponding depression which has never been observed with ozone. The refreshing exhilaration and freedom from languidness are perfectly normal conditions due to freedom from depression resulting from odors and excessive heat. It certainly gives relief from excessive heat, not, of course, by reducing the temperature but perhaps by providing better skin radiation. The effects are not psychological or imaginary for the most striking results have been observed where teachers and pupils were unaware of the presence of ozone.

The long continued test under actual conditions has proven that the effect has not worn off. Nature has a way of adapting herself to new conditions and it was interesting to observe that teachers working in this odorless air now for the second year were just as quick to detect the absence of the ozone as they had been at first. The sense of smell is not dulled by ozone in any degree nor is there anything like anesthesia of the senses or other organs. Oxygen is odor-

less and ozone is received as oxygen until the concentration reaches a point of irritation when it is recognized by the odor.

The discovery that ozone in ventilation prevents fatigue is so important that some fuller statement is desirable. That it is a fact is attested by all who have had irksome duties in ozonated air. The engineer has no right to discuss matters of physiology and medicine but he might be pardoned for suggesting unofficially some things that may be discovered and reported in the future. The sense of fatigue may be due to the presence of waste matter in the muscular tissues. As a higher oxygen content of the blood would hasten the removal of the waste, fatigue would quickly disappear.

During the epidemic of influenza of 1918, the writer accidentally discovered that very few motormen of the street car service contracted the disease. As the car controllers emit considerable ozone it was surmised that this might be due to the ozone. Further inquiry was made as to the immunity of employees in offices having ozone. All that could be found with such ventilation reported that none of the employees so working had contracted the "flu." This looked like a promising lead. The second epidemic was very severe in the city and while it was at the crest the writer called on the house man of the Brown Shoe Co. which has the main offices supplied with the ozone. He stated that of the whole force of several hundred persons only two were out with what they called the influenza but neither of them lost more than three or four days. The floor manager of the basement of the Grand Leader store stated at this time that his absentees list was not greater than at other seasons, and that the absentees were at home nursing members of their families and that none had suffered from the influenza.

This is most startling information. It can be explained only by the fact that ozone increases the oxyhaemoglobin of the blood and thereby increases the resistance of the body to all disease. About 90 per cent of the blood are devoted to the oxidation process while the 10 per cent are nutritive. A person will live several weeks without food, several days without water and two minutes without oxygen. Oxidation seems to be the critical process in assimilation. This would seem to be a fresh field for physiological and medical research. Ozone has been used with great success by both inhalation and by incorporation into oils in the treatment of pneumonia and tuberculosis. Blood tests have shown a rapid increase in the haemoglobin of the blood from the inhalation of ozone. The medical treatment in the use of iron and arsenic for anaemia is for the purpose of making the nutritive ten per cent of the blood more susceptible of assimilation, whereas increasing the oxygen of the blood may effect greater results in assimilation.

This digression is made in the hope of shortly seeing ozone put an end to the numbers of anaemic children that have steadily come from the schools. It is hoped that this perfect air may enable the cities to dispense with the open air schools.

The ozone in ventilation must be put on the same rigid practical basis as the heating system. It must have a standard of concentration based upon a mechanical unit and capable of convenient manual control or of automatic control, using chemical processes as a check only. With such equipment kept clean as it must be to be effective, no apprehension need be felt that results will not follow as indicated in previous papers.

DISCUSSION

THE AUTHOR: The purpose in presenting this additional paper was in a measure, to answer some of the questions that have come up since the previous paper was published. The paper read in the January meeting brought a great many inquiries. The title of this paper was selected with a view to emphasize a point that was discovered in the work done in the St. Louis Schools. It would seem that the failure to bring ozone into general use in the past, has been due to the attempt to use a high concentration of ozone. We find that one of the first things to be established is to see that ozone becomes odorless. It was also found that quite a concentration of ozone may be used and yet not produce an odor. An attempt was made in these school experiments to set people right upon the question that ozone, when made properly, does not produce an odor when in suitable concentration for ventilation. The use of ozone has continued now for two years. It was my purpose in the beginning to put it into actual operating conditions in a full-sized school so that the results could be determined by official medical inspection, which we have had in our schools continually.

An experiment was made in one of our school buildings to test the efficacy of ozone as a deodorizer in a very bad toilet room. The floor of this room was of cement and had become very porous, absorbing odor-producing matter that could not be removed by any cleaning process. The room had become a nuisance to the class rooms above, from odors coming up through the doors and corridors. An exhaust fan had been installed in the toilet room; but this did not abate the complaints. Two units of ozone generators were installed in the room midway between the place of origin of the odors, and the door leading to the corridor. This immediately helped the situation; but it was apparent that not enough ozone was being produced so the third unit was added. This acted as a curtain to effectually cut off the passage of any odors through the door to the school. The exhaust fan was stopped and no further complaint was made of odors. After a two months' trial some odors were still detected near the bad floor section; but no ozone odor was noticed in the room. It was observed that the objectionable odors gradually became less and after four months trial all odors had disappeared.

I do not want to be quoted as recommending such use of ozone as a substitute for ventilation. It was simply an experiment to determine whether ozone would correct an extremely bad case. It was one of those troublesome cases that had reached the acute stage. It was said: "If you can stop that odor you can do anything with ozone."

Our work with ozone during the past two years has been devoted to discovering what the truth was. A controversy had existed for some time with apparently some reputable people on both sides and the result of the perusal of this so-called literature is con-

fusion. Had credence been given to all the adverse statements published, no further effort could have been justified. I think some experimenters have used impure ozone, that is, have had nitrogen or other compounds mixed with it. Ozone produced by the arc or by very high voltages necessarily produces nitrous oxide and perhaps other combinations. High efficiency is not the first consideration in producing ozone. The purest ozone we have been able to produce is obtained with 3,500 to 4,000 volts with a dielectric of 0.040 and with which our results have been obtained. We are extending the use of ozone to many more of the St. Louis Schools in all sections of the City and the tabulated results of this experience will be available for the next meeting.

J. R. McColl: I would suggest that our Research Bureau make a complete review of all literature on the subject and if possible get Prof. Allen to co-operate with some physiologist, as perhaps Dr. Lang, of the University of Minnesota.

The President: The question of the use of ozone is one that has interested me at various times, and the thing that interested me particularly, is the fact that this question comes up about every five years, receives a considerable amount of attention, becomes quite prominent in our literature; then dies out again, only to reappear at some future period. That suggests two things: one that there is quite a demand for ozone, and the other is that there is something wrong with the application; because if it will reoccur at stated intervals, there must be some reason for it, and if the people who install ozonatory apparatus discontinue to use it, there must be something wrong with it. I think Mr. McColl's suggestion that our Research Bureau take the matter up is a good one.

No. 570

OBSERVATIONS OF AN AUDITORIUM HAVING AIR INLETS IN THE WINDOW SILLS

By Samuel R. Lewis, Chicago, Ill.

Member

THIS study was made particularly to determine the effect of the unique arrangement of inlets and outlets on the distribution of the fresh air. Figs. 1 and 2 show the plans of the basement and of the room which is a semi-detached combination auditorium and gymnasium, with the stage at the east end and a balcony along the north side. Experience has shown that the usual room of this type, having no basement, exposed on three sides and losing heat into the ground as well as through the roof, is a difficult problem for heating. Its use is generally intermittent and is often permitted before the walls and furniture get warm. Consequently there is a tendency in such rooms for the entering air to be very hot, for the floors to be too cold, for the balcony to be too warm, and for much trouble.

In designing this plant an attempt was made to overcome these objections. The fact that the room is used as a gymnasium militates against direct radiators, yet it is important to provide for some little heating without the necessity of running the fan. Steam is furnished from the central plant for the entire school building, at about 35 lb. for operating the engine, and at about atmospheric pressure for supplying the radiation. The auditorium has a separate fan and engine, so that it is independent and may be used at times when the school is unoccupied. Cold air from outside passes through tempering heaters capable of heating it from zero to 10 deg. The air passes a steam jet humidifier and enters the fan, which delivers it at a controlled temperature of about 65 deg. into a masonry tunnel which extends along the south wall. This air is allowed to pass freely from the tunnel through the space between the auditorium wood floor and the concrete sub-floor, in channels formed between the nailing strips. Thus, as soon as any air becomes heated and begins to pass down the duct, we begin to warm the floor. The floor, it follows, is always dry, and we need fear no warping or rotting out. Yet, since we have automatic control of the duct tempera-

Presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

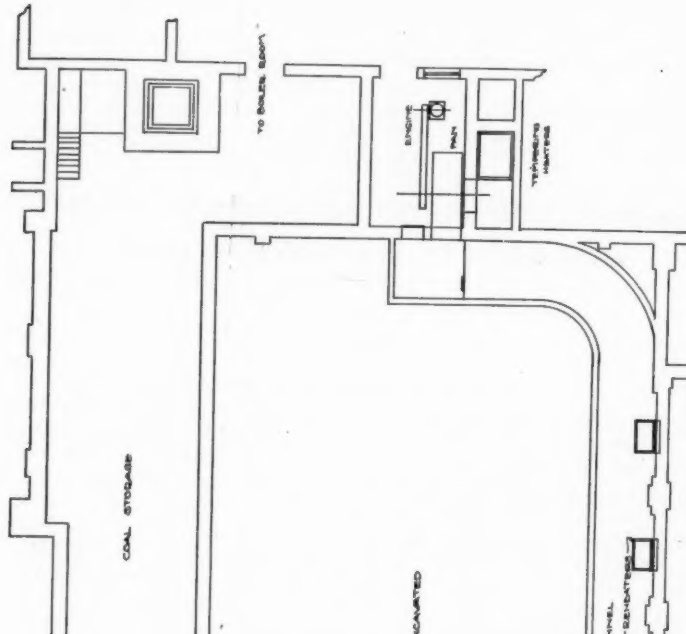

FIG. 1. BASEMENT PLAN OF AUDITORIUM

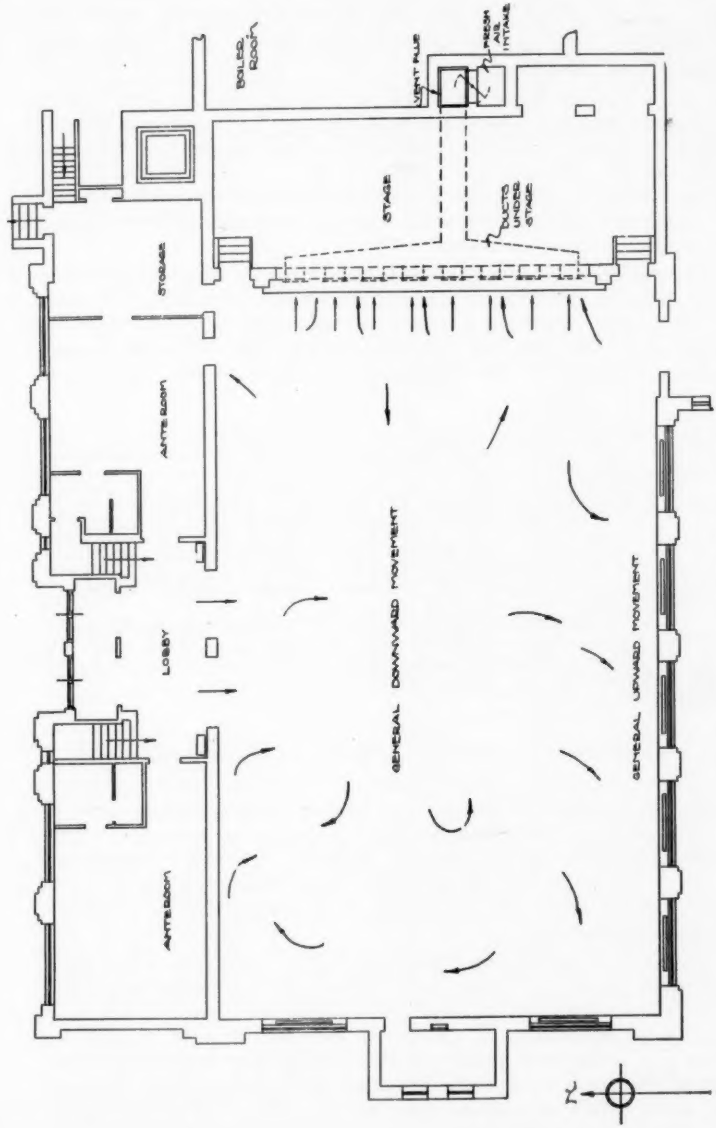

FIG. 2. FIRST FLOOR PLAN OF AUDITORIUM

ture, we are in little if any danger of overheating the floor. By "overheating" we have reference to comfort, not fire. There is no possibility of the latter.

At six stations down the length of the tempered air duct (which is large enough for a person to walk through) are cast-iron indirect radiators, housed in, so that each shall deliver its quota of warm air independently through steel ducts to grills at the sill line of the seven windows. The ducts are insulated against the cold. The air is discharged into the rooms in nearly a vertical direction, though the grills are set at an angle.

The temperature of the room is controlled by thermostats which turn steam on or off these reheaters as required; insurance to some extent against drafts due to too great difference in temperature between room and entering air is obtained by the independent automatic control of the duct temperature. Some human factor will

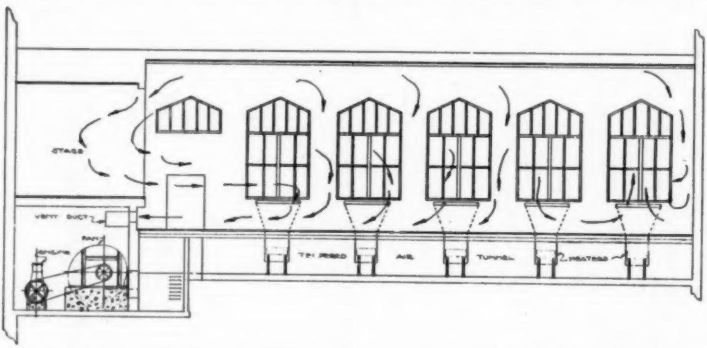

FIG. 3. LONGITUDINAL SECTION AT CENTER OF ROOM, LOOKING SOUTH

always be required, however, with such a control arrangement, as in mild weather, when with a crowd of people in the room, a duct temperature of as low as 60 deg. might be desirable. Again, due to heavy occupancy and sunshine, the room might become so warm that entering air would create an unpleasant draft if below the critical temperature.

The air is removed from the room at the floor line in the front wall under the stage. It passes, in a metal duct, to a masonry chimney. By manipulation of some cross-connecting dampers when desired, prior to occupancy, the air in the room may be rotated for quick and economical heating. The heating and temperature control of the room is reported as quite satisfactory during the year and more, which has elapsed since its completion. We were unable to secure heavy enough occupancy of the room to make a test of any value with carbon-dioxide samples.

We are interested particularly in determining the effect of the inlet and outlet arrangements on air diffusion throughout the breath-

ing zone. We consider that possibly the air circulation within this room may be an index of the circulation and diffusion which would occur using unit heaters in front of windows in a class-room. The observations were made November 19th, 1919, and November 26th, 1919. The currents were studied by observing the smoke from Chinese punk. The observed temperatures November 26th were as follows:

Outside	26	deg.
Tempered air	65	"
Hot air	132	"
Floor in center of room	60	"
Three feet above floor in center of room	66	"
At balcony rail	70	"
Twelve inches below ceiling in balcony	76	"
At vent grills	62	"

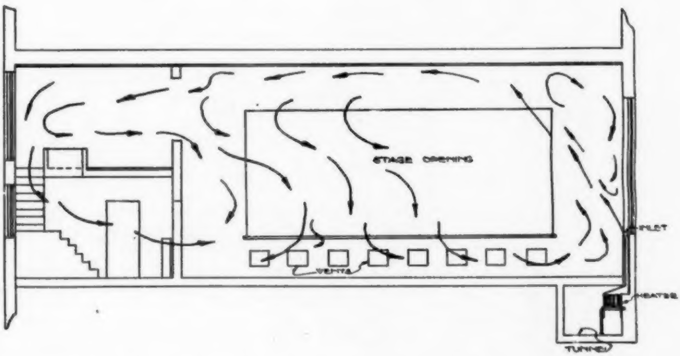

FIG. 4. CROSS SECTION AT CENTER OF ROOM LOOKING EAST

The sense impression as to distribution of air was extremely favorable. While no unpleasant air currents were observed there was a noticeable movement and a decided sensation of freshness. Each inlet discharged about 675 cu. ft. per minute, and the general movement of the air was toward the northeast. At the breathing zone, however, there was no such general movement; the currents at a large number of points all about 3 ft. above the floor, were as shown on Fig. 2. Analysis of these shows the following:

1. A current toward the vent outlets.
2. A current down the balcony stairs and into the room through the entrance doors.
3. A current toward the windows, due doubtless to the injector-like action of the inlets.
4. A general downward movement near the center of the room.

Fig. 3 is a longitudinal section through the room, looking east.

The entering air rises toward the ceiling, carrying along with it air from the center of the room, and the cold down current from the window. Passing along the ceiling, this warm current circulates across the stage, and at a pleasant rate of speed strikes the faces of the audience. About two-thirds of the way across there is an eddy, and part of the air returns along the floor to the vent, while part passes to the sides and rear to the injector-like window currents.

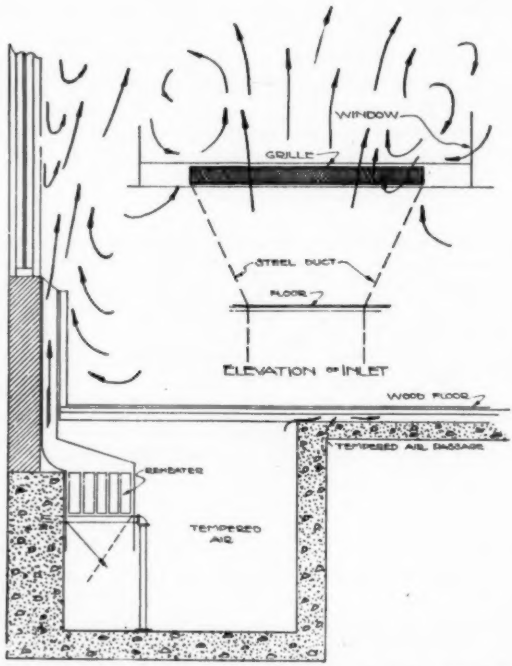

FIG. 5. PLAN, ELEVATION AND SECTION OF AN INLET GRILLE

Fig. 4 shows a cross section through the room looking north. The entering air passes up in front of the windows, then across the ceiling and out into the balcony. The balcony, while not overheated, is very comfortable, and the cooling effect of the few windows there appears not to cause any objectionable drafts at the floor. Much of the air passes down the stair and runs in a stream out into the main room, as indicated on Fig. 1. The temperature of this stream is affected by the radiators in the stair hall and seems to be satisfactory.

Fig. 5 shows plan, elevation and section of an inlet grille. Air currents are plainly observed as shown, and are excellent illustra-

tions of the resistance inherent in air handling. The entering jet seems to affect all of the otherwise quiet air around it and to pull this along with it, somewhat as a spoon in a bucket of cold molasses is followed by a clinging mass. It appears that this very tendency of air to resist stirring has unwittingly been used to advantage in this installation. The psychological reaction from the air entry at the window cannot help but be favorable. The supply of fresh warm air is at a point where one may feel it and test it by sense of smell, if

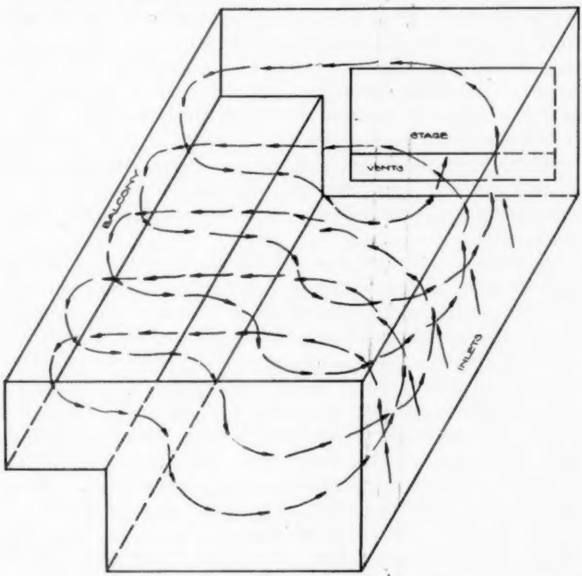

FIG. 6. SKETCH SHOWING GENERAL CORKSCREW LIKE AIR MOVEMENTS

he desires, without having to do so involuntarily. This makes for a belief in comfort.

There seems to be no reason why the stereotyped and time honored point of entry in a horizontal direction about 8 ft. above the floor should be perpetuated. It was undoubtedly used at first as a matter of convenience and necessity, without consideration of diffusion. In many buildings very fine results have been obtained with window-sill entry, particularly where it is impracticable to use inlets under the seats. It can hardly be claimed that such a point of entry gains ventilation by displacement, but it seems evident that lively upward currents of warm air in front of windows improve the dilution method of ventilation to a remarkable extent and tend to discourage stagnant pockets and promote general air movement while being free from unpleasant drafts.

We believe that the conditions would be improved if the inlet were a continuous slot, tending to create a more uniform whirling movement of the entire aerial contents of the room. We call attention to the fact that the general whirling or corkscrew-like movement here, and the one which in our judgment is of major importance, coincides with our observations of the best Chicago class-room ventilation. Here the corkscrew lies horizontally; there it had a vertical axis. The ordinary class-room having the fresh air inlet on an interior wall, discharging toward the windows, with direct radiators under them, is in a chaotic condition as to its air diffusion. The whirl induced by the inlet is opposed by the whirl induced by the radiators, and by all our standards of gauging, the results are unfortunate. When air inlets and radiators are combined, so as to increase the whirl and embrace the entire room content, diffusion is improved. We have an example of a high school which has its direct radiators on the same side as the fresh air intake flues, on interior walls, which bears out this theory, for this large, modern, if radical plant in northern Illinois has been in operation since 1916, with satisfaction.

In connection with the tests of the auditorium we observed, in the academic part of the building, what effect opening windows in one room had on the ventilation of other rooms. The plant was designed with the intention of permitting the utmost freedom on the part of the occupants as to opening windows. The air is delivered to all the rooms in a horizontal tunnel of large cross section under a fairly heavy static pressure, but at a low velocity. It is throttled at each flue base, passing up the large vertical masonry flues at comparatively low speed. On November 19th, the wind was light. Rooms on the leeward side, superimposed, were tested. An anemometer was placed over the inlet of room A and observed. All the windows in the other room B were then opened wide. No change in the velocity at the inlet of room A could be observed. The anemometer was then placed in room B, and room A windows were opened, then closed after a few minutes, without changing the anemometer speed enough to be observed in a run of a minute.

No. 571

THE VENTILATION OF LARGE AUDITORIUMS

By Ray S. M. Wilde, Detroit, Mich.

Member

THE discussion of this subject will be confined principally to the modern type theatre and treated from the standpoint of the practical application rather than as a purely scientific analysis of the theories of air movements in large rooms. In the final analysis of the proper type of ventilation system, I have tried to catch the general public view, for it must be borne in mind that the success of any undertaking must be measured by the opinion of the public mind.

When man roamed at will enjoying all things beautiful, he breathed the pure ozonated air of the new earth unmindful of the problems of sanitation. But, with millions of poor humans trying to be healthy and happy in the artifical confines of the large cities, all this is changed. Man's early desire for education and pleasure developed in him the desire to meet other members of the race in social discourse, these first meetings doubtlessly being held in the open air, where the only universally successful type of ventilating system was adequate to meet every need. Later there was the amphitheatre with its surrounding walls, and banked seats, open to the sky; here also the problem of ventilation had not presented itself. After a few centuries, there was the predecessor of the modern theatre, the old opera houses of Europe in which some attempts were made to provide ventilation; as a rule, however, the natural movement of the air was thought sufficient, as in all buildings of this character there is considerable movement of air, due to varying temperatures of air currents, caused by high ceilings and balconies.

It has been my fortune to design in the neighborhood of 100 systems of various types in varied classes of theatre buildings and it seems to me that we are just beginning to know the proper type of system to install to give the nearest to perfect satisfaction. There are three potent factors that enter into the design of a ventilating system for a moving picture house, other than the scientific calculations, and they are: *cost; operation and maintenance;* and the *architect.*

Paper presented originally before Michigan Chapter; also at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

The first factor of cost interests the owner; usually his chief concern is to know the number of seats he can cram into a certain space, and the size of the money bag at the end of the week. After "sitting in" in many arguments with the owner and the architect, and feeling that they are convinced that a good ventilating system would be an asset, we find that our "Waterloo" comes when they ask "What do your consider the best system of ventilation?" adding, that Mr. Smith has the mushroom, washed air type and likes it, Mr. Jones has the side wall inlets, supply fan without air washer and likes it, someone else has a couple of disc wheels in the attic and says it's the only system, and so on. Here the engineer must use tact and diplomacy, for in making a man invest several thousand dollars in a ventilating system, one must be sure he is going to be satisfied with it when it is in operation.

Operation and maintenance enter into the cost and concern the owner to the fullest extent. The plant must be simple and fool proof, as the helpers usually found around a theatre for this work are not sufficiently trained. Many an excellent system has been given a knockout by some poor fellow bungling a complicated system, because he couldn't help it.

The architect is our best friend and yet our worst enemy, for he designs beautiful interiors and yet does not seem to realize that space is necessary for heating and ventilating apparatus. Many of us have pondered and worried for days, trying to squeeze two fans and an air washer into space where one would fit tightly. Then too, the architect does not like radiators, nor the grilles we must have to let air in and out, and countless other details, too numerous to mention.

We have installed almost every combination of system that could be devised and most of them have worked out successfully. I shall now describe in a general way several of these systems, first the apparatus and then the different schemes of air entrance and exit.

The one way mechanical type of ventilating system is one having a supply fan with tempering stacks, discharging air into the auditorium, at the side walls about 7 ft. above the floor, heated air in winter, and air as received from the outside in the summer time; foul air is exhausted through ventilators in the roof. The two way type has an exhaust fan in addition to the supply fan as described for the one way type. The three way type has a main supply unit, main exhaust unit, and an auxiliary supply unit which is installed in the attic, usually consisting of one or more large, slow speed disc wheels, drawing air in directly from outside and discharging it into the auditorium at the ceiling. When the purse strings are flexible enough, air washers are installed as well as temperature and humidity controlling apparatus.

The question of air distribution is one that has been given considerable attention, but there still seems to be a great divergence of opinion as to the proper methods or locations for air entrance and exit. In order to bring the matter up for discussion let us consider

several types that I have experimented with. The first is what is known as the "mushroom" type, which is primarily an up-feed system; a large plenum chamber or duct is usually placed under the main auditorium floor, and mushroom ventilators placed under each seat; in the balcony, the space underneath is used as a plenum chamber and mushroom outlets are placed under as many seats as possible. Fresh air is forced into the auditorium through these outlets and is supposed to rise to the ceiling where it is removed by an exhaust fan in the attic. A small amount of air is usually exhausted at the floor near the orchestra pit to overcome draughts from the stage.

The theory advanced for this system is that heated air rises, and therefore, with an even distribution of upward moving air, this is a perfect system. This type of system is very popular in some parts of the country, but I suggest that it is not sound in theory. While it is true that heated air rises, what happens to it when it meets a colder, heavier body of air coming the other way?

There are two objections to this system that are enough to condemn it from the viewpoint of the public; one is the chilling effect on the spine of this stream of air coming up around one's feet; the other is the fact that one is breathing air that has come up from the floor, by his feet and over his clothing or that of somebody else—nothing to be alarmed at, but not a pleasant thought.

The next system we might call a combination side wall and mushroom system. In this type, the air supply for the main floor is blown in from side walls about 7 ft. above the floor, the balcony being supplied by mushroom outlets under the seats from a plenum chamber under the balcony. This system is a combination up-feed and down-feed. An exhaust fan is used, taking 75 per cent of the air up and 25 per cent down at the floor.

This scheme works well for the main floor, but it is impossible to keep the temperature down in the balcony. I have in mind a certain job where this scheme was used, in which a temperature of 72 deg. was maintained on the main floor with 70 deg. outside, but there was a temperature of 87 to 90 deg. in the balcony. The owner complained bitterly about this and we were given a free rein with the equipment on hand to improve the results. I had the opinion that we needed more air action over the balcony, so we installed two disc fan wheels in the attic, drawing in outside air, and discharging it into the auditorium over the balcony through the ceiling. The results were marvelous, for we were able to reduce this temperature difference to 5 deg. and everybody was satisfied. This was really the beginning of the so-called three way type of ventilating system which we have used quite extensively.

At this point let me suggest that some movement should be started very soon to establish uniform laws in all states, governing the ventilation requirements for various types of buildings, based of course on the answer of our Bureau of Research to the vital question:

What is Proper Ventilation? Almost every state, city or hamlet has a ventilation code all its own, setting forth a minimum requirement that means very little, and often creating hardships by inserting some peculiar requirement without proper study of the entire problem. To my mind, this code writing is an engineer's job, and we should not sit by and let laymen and lawyers make codes, governing engineering work.

The modern theatre presents several phases of the ventilation problem that are not easy to solve, but I believe we are nearing the solution today. Two types of theatres prevail today, one known as the legitimate house, which shows the large productions, and the other, the large movie house as we know it.

In the legitimate type, not more than two performances are shown in a day; during each performance, the auditorium is occupied for about 2½ hours, and it is entirely possible to maintain a good standard of ventilation for this short period with comparatively small apparatus, provided some thought is given to the proper condition of the air within the house before the audience enters. If a standard of 60 deg. fahr. with about 40 per cent relative humidity is set up in the auditorium as the audience enters, and this is maintained at the apparatus during the performance, splendid results are possible.

The large movie house, which is usually about 75 per cent full for 10 or 12 hours each day, presents a problem that is more difficult to solve. We have tried several modifications of the three way type and have found the following arrangement to give very good distribution and even temperatures: A main supply unit to supply air to auditorium main floor from the side walls at a rate of 20 cu. ft. per minute per occupant, and a main exhaust fan of equal capacity, exhausting 50 per cent of the air from the floor line and 50 per cent from the ceiling at rear of balcony. We provide an auxiliary supply unit of sufficient size so the combined capacity of supply units will change the air in the auditorium every three or four minutes, the auxiliary supply unit being in the attic and discharging air over the balcony, running full capacity for summer and about one-half capacity for winter service when required. This system is one of the best thus far developed and will give very good cooling effects by the absorption method during the summer months.

There is still another system which I shall mention in order to get it under discussion, and that is the down-feed system, where the fresh air (cooled or heated) is supplied through the main ceiling and the foul air exhausted at the floor line. Carefully designed, it is my opinion that this is the best method of air distribution for a large auditorium.

We might mention the cooling system using refrigeration. Those that have been installed are quite successful, but the average installation requires an initial investment of about $30,000 in addition to the regular ventilating equipment and about $75 per day for operation cost. It costs $3,000 per degree of cooling effect, a 10 deg.

difference being guaranteed. If our theatres were built like cold-storage houses, this could be done more cheaply, but the building cost would then be considerably more than the cost of the refrigeration apparatus. There is also a question in my mind as to the effect of the lower temperature on the general health of the public with this type of system.

DISCUSSION

H. M. Hart: I am not going to back down entirely on favoring floor introduction of ventilation, as I am not quite ready for that. There are objections to floor introduction; but if properly controlled, I cannot help but feel that better distribution is obtained with introduction through floor ventilators. My observation has been that going into auditoriums that are ventilated with that system, properly operated and controlled, the sensation is generally pleasant, and the air is fresh and free from odors. With the other systems drafts are encountered and the distribution is not obtained, resulting in air pockets. I have seen some cases of the floor introduction where results were unpleasant; but it is merely the fault of the operator of the plant, and not of the system at all. For that reason it has been condemned, and I don't think it is fair to condemn a system because some operator does not do his duty. There is one auditorium in Chicago where the air for the auditorium, which has two balconies, is introduced entirely through floor gratings on the main floor. Careful records of temperatures have been kept all over auditorium and balconies for four or five years, four readings being taken during each performance. During the cold weather the temperature never rises above 72, at any point, and in order to obtain that result, the temperature of air that is introduced through these ventilators under the seats, sometimes goes down as low as 60 deg. It has been my observation that one cannot introduce air under the seats or at a lower temperature than 66 deg. without having it objectionable and not over a velocity of 100 ft a min.

The President: My experience has been that the mushroom system of introduction is satisfactory where there is a good temperature control.

H. M. Hart: I am not strong for automatic control of the auditorium with the floor introduction system. I think if the operator is wide awake, he can get better results with a hand control. For with the automatic control there are sudden changes of temperature and a sudden change of temperature is objectionable; while with hand control, the man with a little experience, observing weather conditions, can tell at what temperature he should introduce the air to get the right results, thereby doing away with the sudden fluctua-

tion. The reverse is true with the overhead system. The sudden change of temperature in introducing fresh air above the head, if it does not strike in the back of one's neck, is a pleasant sensation, especially when it gets very warm or cool in the auditorium. I am not in favor of trying to maintain absolutely uniform conditions of temperature. It may sound as though I were contradicting myself, but in speaking of the two systems, there are two things to consider, one is the floor introduction system and the other the overhead introduction system. In the overhead introduction system, the changes of temperature are not objectionable and not so noticeable. The fact that it strikes one in the face is rather a pleasant sensation.

A MEMBER: Some years ago, I made some tests on theatre ventilation before the mushroom ventilator was designed, and the air was introduced at the floor at an exceptionally low velocity. The velocity was so low that it was practically impossible to measure it. I could feel it by wetting my hand, and the air was distributed about the room by using the basement of the theatre to get funnel chambers, and it came through the legs of the chairs, through 3½ in. holes, and through the wood work in the floor. It was then distributed through lattice work. In running these tests, I had the air analyzed very carefully by chemical analysis. The building was used for two performances a day, evening and afternoon, every day in the week. The ventilation obtained there, was practically as pure as outdoor air. We were getting perfect ventilation with a diffusion over the entire theatre so gradual that no one noticed any air flow. I experimented with the audience by changing the temperature to 55 deg., and the audience began to cough and get restless as though they were cold. They didn't know what was going on; but the average temperature for the breathing line was about 70 deg. which checks very well. I checked my temperature at the time and it seemed to do very well with the amount of heat that was expected to be given off from the body sitting quiet, and from the experiment I made, there, I am strongly in favor of properly designed ventilation, widely distributed and diffused.

No. 572

THE TRAINING OF JANITORS AND CUSTODIANS

By E. S. Hallett, St. Louis, Mo.

Member

MUCH discussion has been given in meetings of this Society to the general lack of skill in handling the expensive and highly developed apparatus now installed in modern buildings. It is complained that the creative thought of the engineer in producing machinery that will adequately serve the building, is wasted in the operation of it by incompetent handling. In most states laws exist providing for the licensing of operators of high pressure plants for safety only, but low pressure heating systems involving even more intricacies are entrusted to the janitor or custodian, who may have no knowledge of engineering of any kind.

This problem confronted the writer in handling the operation of the school buildings of St. Louis, in which about 200 boilers, an equal number of engines and blast fans, air washers, heat regulation systems, vacuum cleaning system, electric lights and plumbing were operated by untrained janitors. Under these conditions, it kept two supervising engineers on the jump to keep the plants all running in any manner. In those days the call for help at the chief engineer's desk was enormous. It was clear that something must be done, not only to relieve the pressure of supervision but to get the results from the heating apparatus that were demanded. It was determined to inaugurate a system of training of the janitorial force that should make the men and women in charge of buildings self-sufficient, except for repairs.

All the head janitors, who in our system are in charge of buildings, were called for a Saturday class from 9:00 to 11:30 A. M. As they were attending on the Board's time, no serious objections were made. It may be said that most of them were skeptical as to any results. It was absurd, they thought, for a janitor to go to school. They could not see that there was anything for them to learn.

The instruction began with lessons on combustion and firing. The principle involved in the smokeless combustion of soft coal in the down draft furnace was analyzed and explained. The correct method

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of firing was taught and the common errors pointed out. The proper regulation of the heat in the hot and tempered air rooms for varying seasonal conditions were fully explained and reviewed. The maintenance of proper humidity in the rooms, by control of air washer temperature was clearly and fully discussed. They were given the real engineering meat in the simplest forms. The meetings became intensely interesting to all the men. Discussions were permitted with the necessary restrictions and the men soon discovered that the meetings actually saved them time and labor. They planned their work to have Saturday free and no longer used the meetings as an excuse for neglected duty.

The Saturday class also enabled the office to keep in touch with the men and furnished a means of giving general orders in a most definite form. It also developed a spirit of building department pride that was very pronounced. It thwarted any discontent before it had done mischief, as without these meetings it would have been impossible to have the close relationship that now exists. Up to the date of organization of this class, no society or association had been formed among the men, but the commissioner of school buildings, Mr. R. M. Milligan, assisted them, about two years ago, to form a Mutual Benefit Association. The outcome of this society has been most satisfactory. It seems to be another tie to link up the men with the building department. The success of all the betterment work with the janitor system is due to the treatment of the men as human beings rather than as machines. They have been shown how to get pleasure out of their work and their position has been raised in the esteem of all fellow employees. Both salary and responsibility have greatly advanced.

The results of this educational work have been most gratifying. The economy in fuel attributed to this is more than $25,000 for this year. The economy in oil and other supplies is very great. No school has been closed a day on account of the heating plant. Only board of education engineers will appreciate this statement. The improved service due to the educational work is the most striking argument for it. The attitude of the force toward the office could only be attained through the maintenance of the close contact of the school. An outstanding improvement was the ability of the janitorial force to adjust the personnel of the instruction department to building requirements. It requires both tact and firmness to protect the whole school from the whims of a single individual and much thought has been given to this most delicate problem.

The results of the Saturday class attracted much attention and a demand was indicated for the opening of a night school under the provisions of the U. S. Smith-Hughes law. Such a night school class was begun at the Central High School with more than 40 registrants on the opening night. The class was divided the second week with the superintendent of heating repairs, Mr. E. L. Stammer, as teacher. These classes have been highly enthusiastic. Practical demonstrations are occasionally made which are much appreciated.

New formulae are tried out and every lesson has some arithmetical drill that is applicable to the janitor work. A complete course of study has been provided and for the first time the school for janitors takes its place with schools for banking and commerce. It would seem to be properly so placed, since it is shown to be useless to install the best apparatus in buildings until a means has been provided for its proper operation.

The great obstacle at present is the lack of a suitable text book. The writer is now preparing a book that may be used as a text book for such schools or as a manual for managers or for home study. It is thought that a book of this practical scope, which has been developed in actual teaching and which has proven its merit by measured results, will largely solve the problems of operation. The table of contents of the forthcoming volume is given herewith:

COURSE FOR JANITORS AND CUSTODIANS

1. The responsibility of janitor to owner: to the public
   Head janitor's control of assistants.
   How to divide the duties.
   Checking up on the work of assistants.

2. Learning the right names of parts of a building.
   The operation of locks on doors, windows and firedoors.
   The location of tools and equipment and proper racks for same.

3. The finish and composition of floors, of plaster, of woodwork, of furniture, of iron and sheet metal and of glazed brick finish, marble, granitoid and terrazzo.

4. The composition of paints, of first or priming coat, of second coat and the use of several coats.
   How to get glossy surface. How to have flat or dull finish.
   Difference between inside and outside paint.

5. Composition of varnishes. Why used.
   How to select the right varnish for any purpose.
   Why varnish shows scratches.
   What checks varnish.

6. Composition of soaps.—lye soap, jelly soap, and soap powder. Why use different soaps for different purposes? Mixture of abrasives with soap. Trade names for soaps.

7. Scrubbing floors. Proper implements. Scrubbing machines. Scrubbing compounds.

8. Cleaning marble and tile. Removing stains.
   Care of marble and vitreous ware.
   Care of enameled iron.

9. Washing windows. Tools and supplies.
   Rigging for the outside.
   Getting glass clean. Getting the polish.

10. Sweeping floors with floor brush.
    Proper care of brush.
    The use of wet saw dust.
    Use of other oily materials.
    How many square feet per hour?
    Handling movable furniture.

11. Sweeping with stationary vacuum cleaner.
    Width of floor tool.
    Kinds of felts or linings.
    Manipulation around furniture.
    Keeping the machine in order.
    The amount of vacuum required to sweep.

12. Heating with steam; boiler setting.
    Detail of grate arrangement.
    Downdraft furnaces.
    Action of downdraft to prevent smoke.
    Proper method of firing.
    Cleaning fires.
    Regulating the doors.
    Regulating the draft.

13. Firing straight grate furnaces. How to avoid smoke.
    The coking method of firing. Other methods.
    The use and abuse of the slice bar.
    How to burn fine coals. How fine to break up coal.
    How to keep coal out of ash pit.

14. Care of the boiler. Cleaning.
    Putting in heads, Putting in gauge glasses.
    Trying safety valves.
    Repairing leaks in the furnace.
    Blowing down the water to remove sediment.
    Damage to boiler from small leaks.
    Handling the broken grate.
    Making emergency repairs on pipes.

15. Handling steam radiators. Cause of water hammer and churning.
    Where "bleeders" are required.
    Difference between two pipe systems and one pipe gravity.
    The vacuum systems. The air line systems.
    How to handle the various air valves.
    Packing radiator valves.
    How to disconnect a radiator in emergency.

16. Operation of pumps. Starting piston pumps.
    Causes of stopping.
    How to start when steam bound; air bound.
    How to pump hot water. How to lift on suction side.
    Packing the piston; packing the rod.
    The cause of pounding.
    Stopping from receiver or governor trouble.

17. Centrifugal and electric pumps. Priming to start.
    Building up pressure. Care of foot valves; lubrication.
    Adjustment of packing. Speed control.
    Locating air leaks. Flexible couplings.

18. Plenum heating systems.
    Fan and engine.
    Lubrication of engine.
    Oil economy.
    Keying up of engine.
    Care of fan bearings.
    Locating knocks in engines.
    Starting and stopping engines.
    Attention to drips.
    Filling cylinder lubricator.
    Detecting trouble by sound; by smell.

19. Hot room and tempered air room.
    Proper temperatures for mild weather.
    Temperatures for cold weather.
    Care of mixing dampers.
    Pulling up cold rooms.
    Adjusting volume dampers.

20. Heat regulation.
    Positive thermostats on direct radiation.
    Rubber and metal diaphragm motor valves.
    Directions for repairs.
    Graduating thermostats on mixing dampers.
    Illustration and demonstration of the various makes.
    How to set thermostats.
    The training necessary to make repairs on thermostats.

21. Air washers. Maintaining proper water pressure.
    Cleaning settling tank by standing overflow.
    Cleaning spray nozzles.
    Regulating temperature to produce proper humidity.
    How to avoid sweating windows.
    Arrangement of thermostats on vento coils; on by-pass dampers.

22. Maintaining even temperature in every room.
    Overcoming strong wind pressure.
    Necessity for keeping windows closed.
    Fallacy of lowering windows from the top.
    Where window boards may be used.
    Attention to vent stacks and dampers.
    What is stuffiness?
    How to avoid drafts.

23. Hot air furnaces.
    How to fire with soft coal; with hard coal and coke.
    How they ventilate.
    How to take inside air.
    How to prevent cold floors.
    How to humidify.

24. Care of hot water heating system.
    Care of fire and how to bank.
    Attention to expansion tank.
    Avoid leaving to freeze.
    Damper regulation by hand or automatic.

25. Hot water supply.
    Steam heaters with temperature control.
    Heating coils in boilers
    To prevent steam in hot water.
    Putting in new Fuller balls in faucets.
    Use of non-scalding valves.
    The necessity for recirculation of hot water.

26. Ventilation of toilet rooms.
    Operation of suction fans.
    Induced draft with gas jet or fire.
    Underground connections to stack.
    Prevention of mixing of air in the attic.

27. Cleaning toilet room fixtures.
    Protecting the finish or enamel.
    When to call the plumber.
    Prevention of freezing.
    Keeping the nickel bright but preserving it.
    General instructions.

28. The care of electric light fixtures.
    Cleaning glass ware.
    Renewing lamps.
    Renewing fuses.
    Preventing use of attachments.

29. Attention to clocks.
    Care of hand wound clocks.
    Inspection of program service.
    When to call electrician.
    Care of pump in pneumatic systems.

30. The care of electric elevators.
    Directions for cleaning controller.
    Renewal of contacts and brushes.
    Oiling and greasing winding machine.
    Cleaning commutators and brushes.
    Cleaning and inspecting hoistway.
    Inspection of cables; counting broken wires.

31. Making reports.
    Keeping records of coal and ashes.
    Making requisitions for supplies and repairs.
    Making inventories.
    Reading meters.

32. The janitor "safety first" exponent.
    Keeping all exit doors unlocked.
    Keeping corridors free of furniture or obstructions.
    Flower boxes and apparatus out of passage ways.
    Care of stairways.

33. Care of lawn and yard.
    Instructions for sprinkling.
    Cutting grass.
    Keeping weeds out.
    How to keep uniform.

DISCUSSION

The Author: It is often claimed that ventilation apparatus is built and installed in schools and public buildings, and then forgotten. Criticism was brought into the last Annual Meeting as to the cause of this, and some thought it was due to inefficiency of assistants who were operating or supposed to operate this apparatus. I promised the Society that at the next meeting I would have something to say on this subject, because for the last two years or more in St. Louis, we have had a Janitor's School and the results obtained have been marvelous.

The janitor problem is one that requires great care and discretion. It was necessary that a system of training be inaugurated in the St. Louis Schools whereby the proper instruction would be given to the men and women entrusted with the care of the buildings. About three years ago the janitors' Saturday class was started for the purpose of securing better operation of the heating and ventilating apparatus. It was necessary to demonstrate to the janitors that the instruction was leading to an elevation of their positions and standing. By degrees the men assumed more responsible duties. The salary increases were given without political or other influences. The instruction is given by teachers taken from the department who are in touch with the work. Instructors taken from the instruction department of the schools could not conduct the janitors' class.

C. W. Farrar: Is there any arrangement made for bonuses for janitors taking care of schools in the saving of coal, etc., so that the janitor of every school can work on the same basis, and be rewarded or given the preference of two janitors who have schools alike and an opportunity to secure a bonus?

The Author: We have no system of money bonuses, but have what I think amounts to even more of an incentive; we make it a matter of pride: we pass these things from one to the other; we bring up matters for comparison in the discussions and if the men are taking an interest in their work it is put on an entirely different basis from the ordinary day laborer's work.

H. M. Hart: I think the Society is very much indebted to Mr. Hallett for presenting this paper, and I hope that it will be endorsed in every way. The great danger in this idea of bonuses for saving coal is that the school suffers from a great deal more harm than it would otherwise; for there is a temptation on the part of the janitor to cut down his supply and ventilating equipment. However, here is a scheme that will educate the janitor to appreciate what a ventilating system is: Anyone who knows about installation will appreciate what an intelligent janitor means. I hope that this movement will become national, and that the school boards in all the cities will inaugurate night schools for janitors, for it will be one of the greatest steps forward that has been taken along those lines in many years.

JOHN HOWATT: I have visited some of the schools in St. Louis, and I was greatly impressed with the fact that the custodianship of the buildings seemed to be in the right hands. Four of the schools were remarkable examples of cleanliness and orderliness from the operation standpoint. As I understand it, the policy in St. Louis is, that there shall be no rigid rules governing the work. In Chicago, and in most of the other large cities, nearly everything is covered by rules which govern. St. Louis is fortunate in that those in an administrative office are not hampered by a set of cut and dried rules which, therefore, results in giving an opportunity for initiative and individual work. On the other hand, of course, it permits opportunity for great favoritism in case administrative officers are inclined to show favoritism. One set of janitors in a school or district who are in favor, could get more than a set of equally competent janitors in another school who happen to be out of favor with the administrative officer; that is why in Chicago this system was done away with. Years ago an arrangement was in vogue by which the salary of each employee of the school was determined by officers of the Board, and it resulted in a janitor's pay going up and down with his political affiliations. To overcome that condition, the engineers of the Chicago schools organized and had a set of rules established that didn't hurt any of them. The method of employment practiced in St. Louis results in a good school condition, and that is because the officials who are at the head of the school building department are honest. The conditions may change in St. Louis sometime when it would be better to have rules for the protection of the employee. The school for janitors I understand is spreading rapidly everywhere. I know this subject of a school for janitors is being taken up in Minneapolis. The President of the Society is interested in establishing such a school in Chicago under the Smith-Hughes Law, not for school janitors alone, but for the thousands of janitors in the apartment houses. There is no doubt, but that such an institution can be started in Chicago next fall with the aid of other people interested in this work. I believe, however, that St. Louis has gone further in this school work than any other city, and there is no doubt, that this work will spread.

J. R. MCCOLL: It was also my pleasure to visit these schools, and I was very favorably impressed. I think they have worked out very successfully the relationship between employer and employee; they have dignified the position of the janitor and have started the children in on an early training of cleanliness. The children, both boys and girls, as they come in from the basement, go immediately to a room provided with large mats, which they have there for them to wipe their feet upon under the supervision of inspectors They first wipe off all the dirt on the mat and then go to a bench and brush their shoes. After that they go past the inspectors and if any pupil's shoes appeared to not have been thoroughly cleaned, he is sent back. They go from there to the main floor and a teacher inspects their shoes and if they are not clean enough, the pupil is sent back under

this second inspection. This looks like a lot of work, but it is quite important. It not only teaches the child to be cleanly, which is of great value, but it also keeps dirt out of the class-room, which is an important feature in keeping the air clean; when we are keeping the air clean, we are really doing something that is good for the ventilation of the class-rooms because that dirt and dust is otherwise scattered in the air and on the wood-work. This produces cleaner air, keeps the class-room cleaner, teaches the child to be clean, and I am very much in favor of it. I have never seen this practice before and I was very much impressed with it.

A MEMBER: I would like to ask Mr. Hallett, whether he has to have licensed engineers to operate the plants here.

THE AUTHOR: The St. Louis Board of Education is in a peculiar situation, for it is a state institution. Our school buildings are in the same status as the government buildings in the city of St. Louis, and employees are licensed by our own department. We have a civil service law that controls. We also have a non-partisan board, the members of which are high up in the scale of public-spirited citizenship and above reproach. They are nominated by both parties. That part of it is a gentleman's agreement, and fortunately they haven't done anything but put up good men. This high ideal of the board is fostered and carried on, and politics never enter at all in any of our work. Our license requirements are higher than the city requirements; therefore, we examine a man who comes in with a city license. If he doesn't have the particular qualification we require in the school, he doesn't pass our examination.

A MEMBER: In Minnesota a new license law passed about two years ago, requiring every man who operates even a low-pressure plant to have a state license. We found janitors who had been in our employ for thirty or forty years who were not able to pass this license examination.

THE PRESIDENT: A state law?

A MEMBER: Yes. It was necessary for us to establish a school to assist these janitors to pass those examinations, and that is the reason why we started a janitor school. It has been in operation over a year, and since that time, probably 60 per cent of the men who took examinations have passed. In the past few months, however, we have found that this school is working as a detriment in one way, for the men are learning so much that they are going outside and getting more profitable jobs. We also find that our course needs some mathematics, although not outlined in Mr. Hallett's paper, because these men ask a number of questions about the construction of boilers and how to figure boiler-horse-power, and so forth, and we find it necesary to give a fairly easy course on that.

THE AUTHOR: This book I am getting out has mathematics in it. We use it in our constructive work, although I have not outlined it, because we have some mathematics in every lesson.

THE PRESIDENT: What does your curriculum include? All janitorial work, or mostly engineering?

A MEMBER: We started out answering all questions that were necessary to pass a state license law, and supplementary to that we took up what we call a "house-keeping end," including the care of furnaces. It is somewhat as outlined in Mr. Hallett's paper but not so extensive.

THE PRESIDENT: At the Semi-Annual Meeting in Pittsburgh, a year ago, this matter came up and a resolution was passed to appoint a committee on grading janitors. In view of the fact that Mr. Hallett has taken up this work, I wonder whether this work should be taken up by the Society or whether it should be left in the excellent hands that it is in at the present time? I don't think any committee could have presented any better report than Mr. Hallett has. It has been tried and found all right, and anyone can see that that is a big step towards solving the question, not only with regard to school janitors but all janitors. Heretofore, it has been thought that any man who could handle a shovel and had muscle enough to throw a shovel of coal in a boiler, would be all right to qualify for a janitor.

A MEMBER: I understand vacuum cleaners are being used in all your schools.

THE AUTHOR: No, probably one third of the schools have the vacuum cleaners in them.

A MEMBER: Have you found that where you do have vacuum cleaners it helps much?

THE AUTHOR: Yes. We had one occasion where they said it was easier to sweep with a broom. Of course that depends on the furniture and equipment, but our janitors use vacuum cleaners wherever possible. They don't use them for all the sweeping, but for the bulk of it, and even if they were disposed not to do it, we require it, because we want that dust out of the house. I wish we had the funds to install them throughout. We would install them in all the schools if we were able. It is a matter of time and money with us to get them.

No. 573

HIGH EFFICIENCY AIR FLOW

By F. W. Caldwell[1], Dayton, O. (Non-Member)
and
E. N. Fales[1], Dayton, O. (Non-Member)

PRIOR to the advent of dynamic flight, little study was made of the behavior of air in motion; but as this new science progresses we may expect contributions from it to the general store of engineering knowledge. Empirical analysis of air flow phenomena has been hampered by the invisibility of air, although theoretical analysis has reached a very creditable stage. Yet theoretical fluid dynamics is not useful unless linked up with empirical data, and the aeronautical engineer so far has very little theoretical background to his design, so that he is as much an empiricist as is the ventilating engineer.

The development of a means for visualizing air flow, reported in this paper, is therefore of interest, as it discloses to us for the first time the empirical facts on which to base our aerodynamical theory. The method of visualization has been used by the writers in conjunction with an extensive study of air flow through propellers, about wings, struts, etc., both model and full size.

The model studies, made in a wind tunnel, have been particularly useful. It is in the wind tunnel that the experimenter reproduces those forces which exist but cannot be evaluated in full flight. The apparatus is really a highly refined flue and, for that reason, of interest to the ventilating engineer. The air current must have a high degree of uniformity, without eddies, in order that the force it produces on the model against which it blows shall have similitude with the force due to the same model moving through still air.

The wind tunnel at McCook Aviation Field, Dayton, Ohio, has a 500 mi. per hour air current 14 in. in diameter, created by a 200 h. p. fan. In Fig. 1 it is seen that the general shape is that of a venturi tube 19 ft. long. The air enters by a carefully designed intake bell, reaches maximum velocity at the throat where it impinges against the aeronautical model under test; and decelerates in the expansion cone, being exhausted into the room by a 5 ft. 24-blade

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[1] McCook Field, War Department Air Service, Dayton, O.

Presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

propeller fan. The unusual efficiency of 76 per cent has been attained by departing from conventional practice. An extensive series of experiments and studies was made on model wind tunnels in order to investigate these novel features; and much of the data produced are of interest not only to the wind tunnel designer, but to the ventilation engineer.

ABSORPTION OF POWER IN VORTICES

Vortices must form in any air flow which is not uniform. Structurally similar to meteorological cyclones, they absorb a surprising amount of energy, very little of which is returned to the stream; in the McCook Field wind tunnel, artificially created vortices have been experienced of such power that they have broken the "straightener" on drifting downstream into contact with it. The vortices set up by a few small ropes stretched across the stream in a wind tunnel may double the resistance of a model in their path (see R. & M. 597, Advisory Committee for Aeronautics, Great Britain).

By visualizing these vortices we are now able to develop our conceptions of air flow. So long as we observe a vortex at its source, we can directly perceive its cause—a splinter, nail head, etc.—but once formed, the vortex drifts downstream more or less intact without any indication as to its origin. In non-turbulent flow the peripheral vortices along the walls are the most noticeable. It is these into which goes the energy lost by wall friction in a duct; they run downstream in large numbers along the walls. Since their velocity of run is only slightly less than the airflow velocity, these vortices or vortex rings appear to the eye as shapeless fog and stroboscopic observation is necessary for proper analysis (see Fig. 2). Those vortices, however, whose axis is parallel to the direction of flow, are clearly observable to the naked eye without stroboscopic assistance.

Fig. 3 shows one of these vortices having a longitudinal axis and trailing off the tip of an airplane wing. Its size, shape, angular velocity and energy content, are definite quantities; when we consider that the eddies and whirls of conventional air flow are merely a multiplicity of such vortices, we are able to revise our imperfect conceptions which until now have been formed during an occasional glimpse of a dust whirl, a smoke billow, etc.

SPIRAL FLOW

Rotary motion of the air stream as a whole is often met with, and is undesirable. In a wind tunnel the radial flow at intake produces a slight whirl tendency; this however, is counteracted by locating a straightener at the pressure apex some distance downstream. The noteworthy effect of this straightener is that in spite of its 30 sq. ft. added frictional resistance, it accomplishes a rise of overall efficiency, and a fall of pulsations from 15 to 3 per cent.

That such spiral motion, even in non-turbulent flow, is wasteful of power was demonstrated by making runs with and without spiral flow in the McCook Field wind tunnel. Before installation of the above mentioned straightener, a test was made to determine power absorption at different speeds, the throat and intake being free. The straightener was then put in place, consisting of two thin plates crossing at right angles, 4 ft. long and located 4 ft. down the cone; and a second power test was run. A second auxiliary straightener, consisting of 16 radial blades, was then brought up against the intake bell, as shown in Fig. 1, and a third power test was run. Thus the power recovery due to each addition was evaluated. Fig. 4 is a curve showing the energy recovery due to the auxiliary straightener, and demonstrates that a gain of 10 per cent may be expected in a case of this sort.

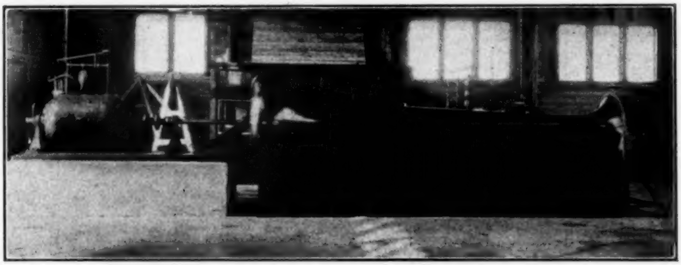


FIG. 1. GENERAL VIEW OF McCOOK FIELD WIND TUNNEL

The spiral flow usually found in ducts fed by a propeller fan has a pressure gradient which increases from the center outwards; the velocity gradient may also increase outwards. We then have induced whirls at the core of the stream, while the skin friction vortices at the periphery are accentuated; and the total energy loss is considerable. The cure is to insert straightener vanes in the duct as near the fan as possible. One redeeming feature of such a spiral flow, however, is that it will fill an expansion cone of higher angle than will true axial flow.

DECELERATION OF AIR

The expansion cone of a venturi tube or a wind tunnel is an important factor, playing a part analogous to the draft tube of a hydraulic turbine. The natural expansion angle during deceleration of axial flow is 5 to 7 deg. If we provide a conical duct of angle greater than 7 deg. we do not alter the actual expansion angle—this remains much as before, and the oversize cone does not fill.

There remains an inert ring of air separating the air-blast from the cone walls and this inert air becomes the seat of many parasite eddies (see Fig. 5). We have here, in fact, the worst case of wall friction, namely, that in which an air stream is surrounded, not by a container, but by air. The thicker is this ring of whirls, the more energy is lost in vortex formation; and the greater the angle of the expansion cone, the smaller is the efficiency of conversion within the cone.

Certain cases were found in our model wind tunnel experiments wherein spiral discharges set up a "virtual" expansion cone with

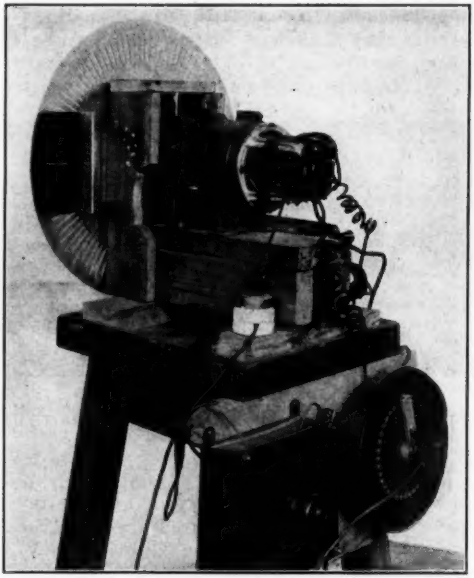


FIG. 2. THE STROBOSCOPE

very noticeable conversion of velocity head into pressure head, although the blast was not housed in any way (see Fig. 6, Runs 24 and 34). In this case the virtual cone did not form of itself, but came into existence after momentary application of a real cone which was subsequently removed. This phenomenon was observed only when the discharge orifice was slightly rounded. Fig. 7, Run 59b, shows another interesting case of a virtual cone, efficiency being fair even with fan removed 0.4 diameter from discharge opening.

VISUALIZATION OF AIR FLOW

Study of phenomena such as above described is greatly facilitated by the method of visualization developed by the writers.

In the past, analysis of air flow has been confined to the use of smoke or powder set loose in the air to indicate lines of flow; or threads in the role of wind vanes; or "yawmeters" connected to a manometer. Or we have been driven to analogies derived from the study of fluids of differing viscosity and density such as water; or, further, we have sought by measurement of static pressures to deduce the lines of flow.

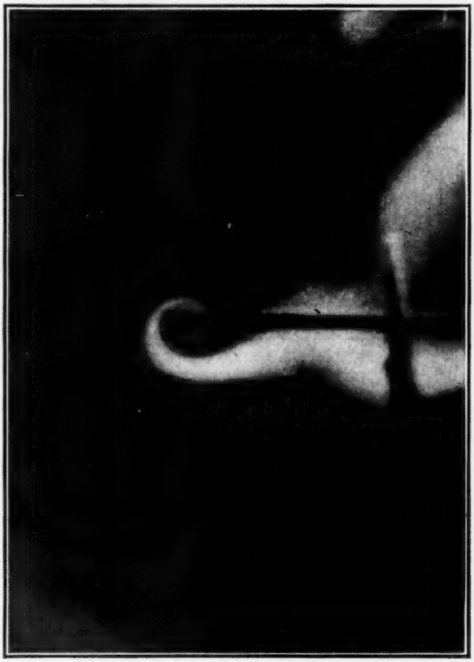


FIG. 3. TIP VORTEX

The new method appears to be superior to these older methods. It depends upon the fact that the moisture in the air condenses out as visible fog when the temperature is reduced to the dewpoint, provided a suitable nucleus is available to start the condensation. In the McCook Field tunnel the temperature drop is brought about through expansion of the air due to 100 in. of water suction at the throat. The relative humidity of the air can be artificially raised if too low. The necessary nucleus for condensation is provided by the models under test, by dust in the air, by minute irregularities in the tunnel walls, etc.

The vortex photograph, Fig. 8, illustrates the use of this method. It shows the character of the air phenomena surrounding a model airplane wing; it also shows, near the walls of the tunnel, some fog spectres that are characteristic of flow in an unobstructed flue.

The photographs are enlargements of a moving picture film, made under illumination by several carbon arc search lights. So far our photographs have been confined to air flow about models, and no adequate photos of the typical unobstructed flow are available. An attempt is therefore made to describe the general appearance of the

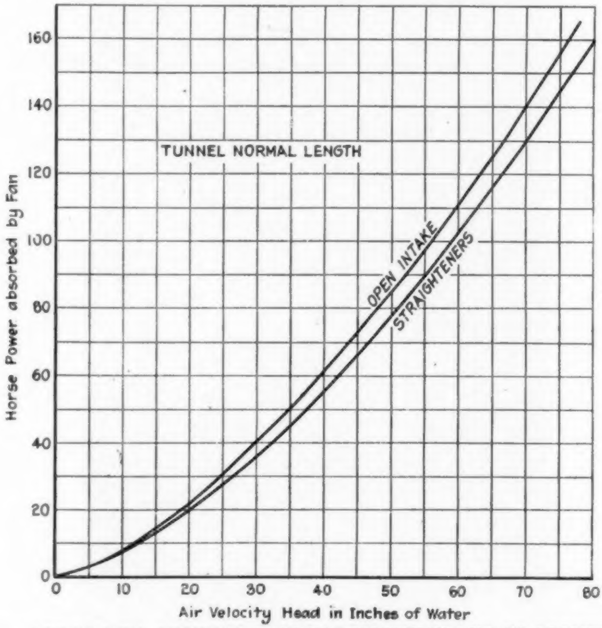


FIG. 4. POWER RUN, SHOWING GAIN IN EFFICIENCY DUE TO PREVENTION OF SPIRAL FLOW BY INTAKE STRAIGHTENER

flow in the throat of the wind tunnel, which may be considered typical of all air flow. The observer is supposed to be looking into the open intake end of the wind tunnel; that is, his line of sight is along the direction of flow.

The general appearance of the air flow, which may be considered typical of all air flow, is as follows: A cross-section at the throat shows a seething mass of fog spectres, denser at the wall than at the center, although occasionally the entire disk fills up with fog to the point of opaqueness. The spectres have, in the cross-sectional plane, a gentle movement like the flame of an alcohol stove, showing the constant readjustment of equilibrium. Vortices and S-shaped

whirls continually form and, after moving about, lose themselves in the general confusion. In a diagonal view they take the appearance of long, foggy fibers, stretching down the tunnel like wooden mould-

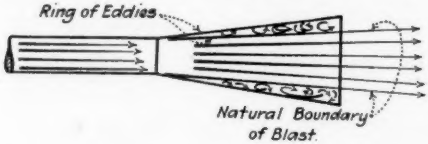


FIG. 5. AIR FLOW IN EXPANDING CONE OF EXCESSIVE ANGLE

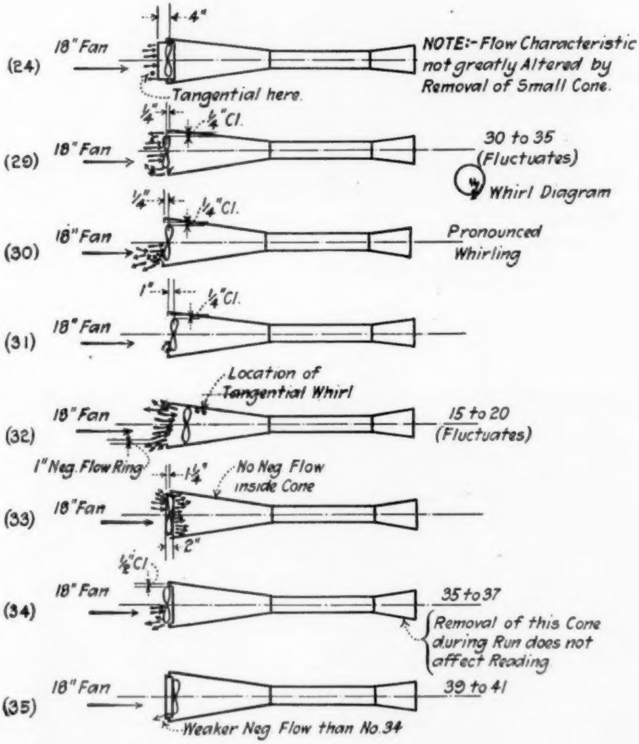


FIG. 6. VIRTUAL CONE FORMATION, RUN 24 AND 34, SERIES I

ings. The axes of whirl, of course, are longitudinal. Under proper humidity and lighting conditions, the whole becomes a beautiful irridescent sight, violet and purple hues predominating.

THE FAN

In the design of a fan and its housing, the fundamental axiom is to avoid eddies; in a wind tunnel the horsepower required may vary 300 per cent according as this rule is followed out. By application

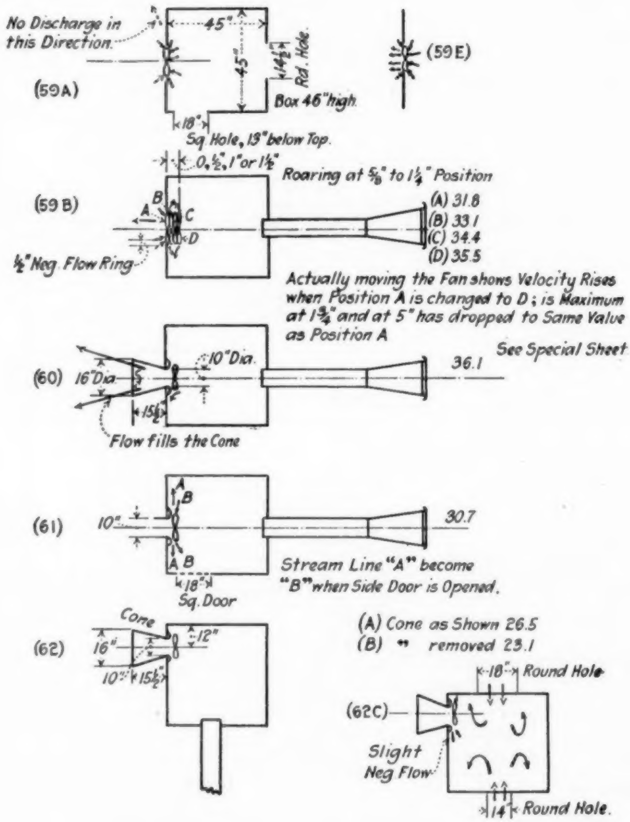


FIG. 7. VIRTUAL CONE FORMATION, RUN 59 (b.) SERIES II

of this rule to the air flow in the tunnel, and by application to the fan of the principles of airplane propeller design, very interesting results can be secured. Thus a propeller fan may be made to operate efficiently under a head much larger than is commercially usual. It may have the advantage over the centrifugal blower of being

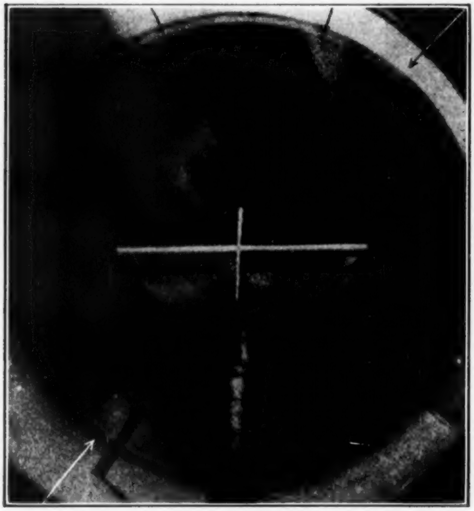


FIG. 8. PHOTOGRAPH OF AIR FLOW ABOUT MODEL AIR PLANE WING, SHOWING FLOW ATTRIBUTABLE TO TUNNEL WALLS

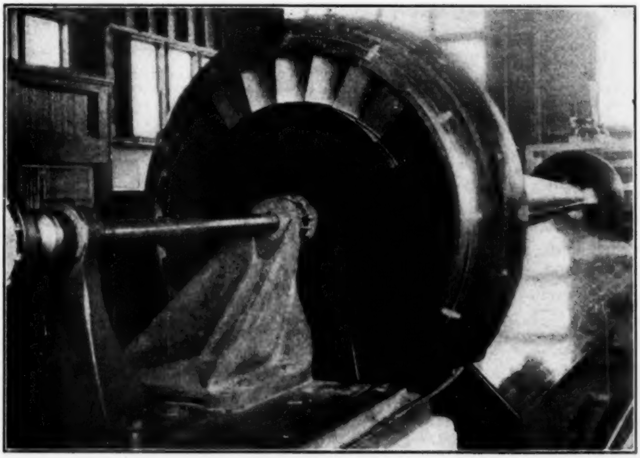


FIG. 9. FAN END, McCOOK FIELD WIND TUNNEL

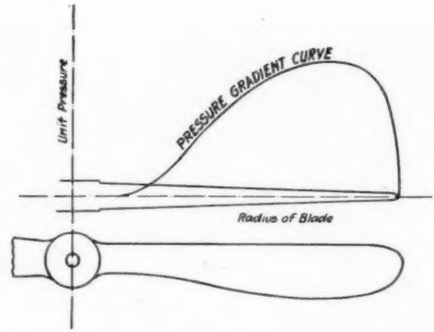


FIG. 10. CURVE OF TYPICAL PRESSURES ON BLADE OF PROPELLER FAN

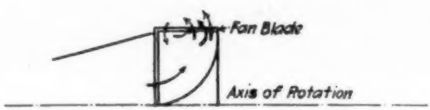


FIG. 11. DIAGRAM OF THE WHIRLS WHICH MAY EXIST ON THE BLADES OF A CENTRIFUGAL FAN

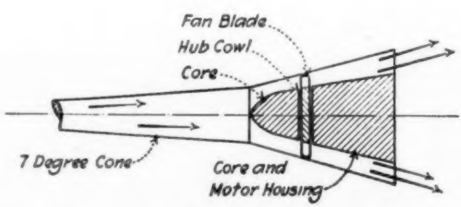


FIG. 12. ARRANGEMENT OF FAN AND CONE FOR HIGH HEAD AND HIGH EFFICIENCY

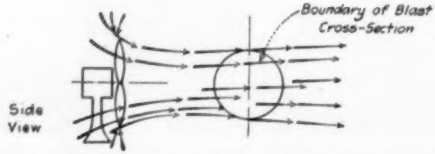


FIG. 13. AIR FLOW THROUGH COOLING FAN OF CONVENTIONAL TYPE

cheap, easy to build, efficient, and compact. Our 5 ft. fan (see Fig. 9) absorbs 200 h. p. and the overall efficiency of the entire plant, wind tunnel, propeller and all, is 76 per cent.

$$\text{Efficiency} = \frac{\text{KE throat} - \text{KE Fan}}{\text{KE Throat}}$$

To understand how this has been accomplished let us consider the pressure distribution over the propeller disc of a conventional fan,

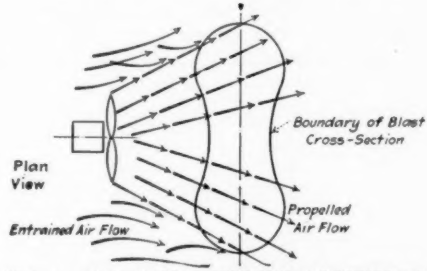


FIG. 14. AIR FLOW THROUGH MODIFIED FAN

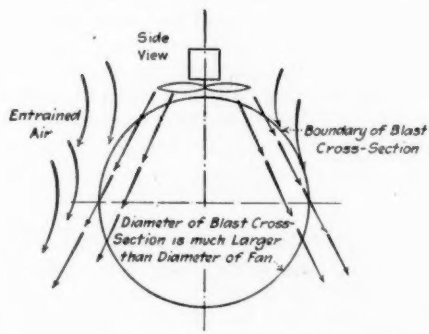


FIG. 15. AIR FLOW THROUGH FAN MODIFIED FOR USE AS CEILING FAN

or what comes to the same thing, over a propeller blade. It is by no means uniform, but varies from zero at the hub to maximum at 2/3 radius, dropping to zero at the tip. Now when we apply such a fan to ventilation and enclose it in a housing we have a very bad combination; for, to make a long story short, the acceleration and race rotation of the fan blast effect a situation such that whirls of great wastefulness ensue. One very noticeable eddy in this case is at the hub, the direction of flow on the downstream side being backwards; see diagram of pressure gradient on airplane propeller, Fig. 10. It is interesting also to note an analogous case on the blades of a centrifugal blower; see Fig. 11.

It is largely this uneven pressure distribution which has limited the usefulness of propeller fans in ventilation work. The remedy lies in making the pressure uniform, and is a matter partly of blade shape, partly of hub cowling, partly of housing. A blade designed for uniform pressure will probably flutter and be noisy. In the McCook Field wind tunnel the desired end is attained by cowling, or blanking off, the fan hub for 2/3 diameter, and by introducing a core upstream to correspond.

Fig. 12 illustrates a combination of fan, cowling, and housing wherein high head is combined with high efficiency, provided the fan is properly designed. The air passages upstream, and downstream are cored and provide areas proportioned to the propeller inflow and outflow accelerations respectively. Theoretically the discharge cone should be a warped surface, but a truncated cone is easier to build.

For ventilation use, many cases can be conceived where such an arrangement, using a wood-blade fan, would be economical. To those who regard the use of wooden fans with skepticism the following considerations are presented:

Wooden propellers or fans are durable where not exposed to water. They are easily made and for high duty in small quantities, are cheaper to build than if made of metal. Since their construction is largely hand-work, special or novel designs cause but little addition to production cost. Wooden blades afford a better aerodynamic shape and better efficiency than is usual in metal blades. The noise making characteristics are more easily controlled. As applied to airplane propellers wooden construction is stronger than steel.

DIFFUSER FAN

An interesting application of air flow principles is in connection with the electric cooling fan. Such a fan is like an airplane propeller rotating at fixed point on the ground, the blast is narrow and of high velocity; see Fig. 13. In the past, attempts to make it spread out over a large area have been unsuccessful; but we can now solve the problem aerodynamically. Fig. 14 shows the widely diverging blast which can thus be produced. Fig. 15 shows a high speed desk fan which has been converted into a ceiling fan by causing the blast to cover a large floor area. Such a ceiling fan does the work of the conventional type, but is smaller, cheaper, and more sightly. Fig. 14 shows how a non-oscillating fan is made to spread its blast over 120 deg., a space equivalent to that covered by an oscillating fan. The divergence of the blast, conical in case of a ceiling fan and wedge-shaped in case of a desk fan, results in a quick dissipation of the kinetic energy. There results a slow flow of large cross-sectional area instead of a fast flow of small cross-sectional area. The volume of air moved, however, is superior; for the dissipation of energy is accomplished by entrainment of the surround-

ing inert air, so that the quantity of air moved by such a fan may actually exceed the amount passing through the blades. More circulation is produced than by the conventional fan. but at low velocity. The breeze is of a character to produce on the observer a sensation quite different from that of the conventional type; violence of flow is dispensed with; the cooling effect is experienced not only on the observer's face, but over his entire body.

DISCUSSION

H. M. HART: I don't see how they obtain this wide diffusion of the air.

FRED R. STILL: I think I can shed some light on that. There are two or three things from a ventilating standpoint that are different from the general run of electric-cooling fans in connection with the air flow principles. The design of the fan he has shown in the air tunnel is altogether different in its operation than when that fan is out in the open, as ventilating fans are normally applied. Take for example, an electric fan on the ceiling: as the fan revolves, a centrifugal motion is set up so air spreads in every direction horizontally as well as downwardly. Now, if we want to stop the radial flow from one of those fans we have to stop the centrifugal action; hence what he says about the angularity of the conical flow is correct. The way we attain it, which also adds very materially to the efficiency of the fan as a ventilating fan, is by shaping the blade with a peculiar tip at the end of the fan blade; it is bent over to stop the radial action. The mechanical efficiency of the ordinary propeller fan is about 25 per cent; but by getting the air to flow in a conical form, about 63 per cent can be obtained. I mention this to show that the author of the paper is working in the right direction. He shows a diagram of a common wall type of fan, and says he cannot show as good an efficiency with that as with the other fans. That is true unless an expanding outlet is attached. A mechanical efficiency of 92 per cent has been obtained by attaching a long expanding outlet piece. One of the greatest difficulties encountered when testing these fans is the whirling motion of the air. The author uses what he calls a straightening device. It has been done for years and one cannot get accurate measurement unless something of that kind is done. Just how much is lost by putting it in and how much extra work has to be done by the fan, we don't know.

A MEMBER: I think when the author speaks of "conventional fan," he means the type of propeller used in airplane work. I am certain of that, because otherwise it is not true. The type of fan, unless it has some way of stopping the flow from the end of the blades will not show any such loss as he indicates. I might say this—that he has discovered nothing new in the type of fan which he shows. In Germany, a great many years ago, a fan was built

that finally resulted in exactly the same type of fan. It was started out with a spiral, that kept on going around, and then it was changed so that finally it became cone-shaped as is shown in Fig. 12 with exactly the same blades on it. It has been in use for about 50 years and I understand the thing is still in operation. There are a great many difficulties one gets into in a commercial application of a fan of that type. There is difficulty in keeping the blades from rasping.

THE AUTHOR: It is a universal misconception that air from an ordinary wall or ceiling fan diverges from the blades. Such a fan sucks air radially inward at the tips, and delivers it with a direction which is towards the axis. Beyond a distance of a diameter or so, of course, the air blast commences to diverge slightly as it slows up, but nothing like the divergence of Fig. 14.

The reason centrifugal force does not act is that it is balanced by a pressure gradient radially outward in the blast. The bent-over tip of blades of the "Blackman" type does not prevent outward radial flow, because there is no outward component; unless of course we run the blade angles up into the centrifugal blower class, when all the flow is outward.

No. 574

THE SIZING OF DUCTS AND FLUES FOR VENTILATING AND SIMILAR APPARATUS

By H. Eisert, Baltimore, Md.

Member

THE sizing of the ducts and flues for ventilating and similar apparatus has been the subject of many suggestions towards some rational method for their proper proportioning. A number of these suggestions have been published in the data sheets issued with the *Heating & Ventilating Magazine,* of New York, N. Y.

While the magazine deserves much credit for the well meant intention, a careful perusal of the offered suggestions, however, discloses the following facts:

1. The velocity of flow, and with that the duct size, is assumed arbitrarily with little, if any, consideration of the amount of the flow.
2. No consideration is given to the possible effect of the shape of the duct, that is, the proportions of the duct dimensions.
3. With one exception, no consideration is given to the possible effect of local resistances and other impediments to the free flow of the air through the ducts.
4. No effort is made to establish the produced resistance head and the correspondingly required duty of the fan under given conditions.

The very fact that so many different methods have been suggested and employed, shows a lack of satisfaction from the standpoint of the engineer. In consequence thereof, the statement, that in each case satisfactory results were obtained, can be considered of value, only in so far as the satisfaction claimed in each case was individual.

This is the more to be regretted in view of the fact that recent development from authoritative and well corroborated researches in this field, make it possible without difficulty to properly consider the above stated omissions, not only to the full satisfaction of the engineer, but also from the equally important standpoint of economical installation and operation.

Paper presened at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

The fundamental conditions, forming the basis for the design of a duct system for a ventilating or similar apparatus, are given in all cases by the quantity of air to be supplied to each terminal and by the local conditions for the arrangement of the ducts and any other parts in connection therewith. The actual quantity of air required in each case may be stipulated by law, or else fixed by special requirements. The arrangement of the apparatus in its various parts, including auxiliaries, etc., depends entirely on the prevailing or otherwise given local conditions as to space, location, special requirements, etc. It is under these conditions that practical experience, with due consideration of the results from the more recent and corroborated researches relating to the object in view, must determine the proper dimensions and proportions of the duct system and the size, kind and type of any required auxiliaries. The designer must also bear in mind the following facts:

1. The movement of air through a duct system can be produced only by maintaining a greater pressure at the starting point than that prevailing at the terminal point of the duct;
2. No such movement of the air can be produced without overcoming the always, and unavoidably so, existing resistances to a free flow of the air in the ducts.

These resistances are caused to a greater or less extent by friction, disturbances of the flow due to changes of the direction of the flow, changes of the cross-sectional area of the duct, the presence of obstructions, such as dampers, registers, special attachments, apparatus, heaters, etc.

Thus, in order to move a given volume of air through a given duct in a given time, it requires a greater pressure difference to produce the necessary velocity of flow than that which would produce the same velocity of flow in an absolutely frictionless duct.

Designating now the latter by h_v usually termed the velocity head and the pressure or head actually required to produce the desired velocity of flow by h_d then the difference:

$$h_d - h_v = h_r \quad (1)$$

represents that portion of the head h_d, which is expended in overcoming the prevailing resistances. The head h_r may therefore be termed the resistance head of the duct. The very fact that, in equation (1), the resistance head h_r is expressed in the same units as the velocity head h_v allows its representation as a proportionate part of the latter in the form:

$$h_r = Rh_v \quad (2)$$

$$\text{The ratio } R = \frac{h_r}{h_v} \quad (3)$$

thus expressing the effect of the resistance to the flow of the air, can therefore be termed the *resistance factor* of the apparatus or of any section thereof, as the case may be.

Furthermore, since the resistance to the flow of air through any apparatus depends solely on the prevailing conditions as to the arrangement and dimensions of the various sections of the apparatus and the presence of local impediments to the free flow of the air, the resistance factor R assumes a distinct and fixed value in each and every case. With the resistance factor R thus fixed by the prevailing conditions, equation (2) shows clearly that the produced resistance head varies directly with the *square* of the velocity of flow, that is, in the same ratio as the velocity head corresponding thereto. This fact should be sufficient reason to limit the allowable velocities in the duct system of a ventilating apparatus so as to assure a reasonable economic installation and operation.

It occurs only too often that, for the sake of reducing the cost of installation, high air velocities are allowed with the result that the correspondingly produced high resistance heads are so excessive as to become prohibitive from the standpoint of economical operation, and even lead to failures in the proper distribution of the allotted air volumes to the various terminals of the duct system.

While it is natural that there should be a tendency to allow high velocities of flow in order to obtain small duct areas, and with that, cheaper ducts, it is also evident that there will be a limit to the allowable velocity beyond which the advantage gained with the small ducts as to cost of installation, is outweighed by the disadvantages of the high operating expense of producing the necessarily high pressures corresponding to the high velocities in the small ducts.

In balancing these conditions against each other, experience has shown that the allowable air velocities should increase with the volume so as to avoid unreasonably large ducts for the passage of large volumes and equally unreasonably small ducts for small volumes of air. At the same time the maximum velocity of the air in any part of the apparatus should not exceed the discharge velocity of the fan.

A comparative analysis of the reports on the operating results of a number of satisfactorily functioning ventilating and similar apparatus indicates that the most suitable velocities in the ducts can be expressed as functions of the volumes of flow in the form:

$$v = 0.6\, V^{1/4} \qquad (4)$$

when $V =$ the volume of flow in cubic feet per hour, and
$v =$ the velocity of flow in feet per second.

The acceptance of this relation establishes at once a corresponding relation between the area of the duct and the volume of flow in the form:

$$a = \frac{0.04V}{0.6\, V^{1/4}} = \frac{V^{3/4}}{15} \qquad (5)$$

when $a =$ the cross-sectional area of the duct in square inches.

By representing the two dimensions of a rectangular duct by m and n, the equation (5) can also be written in the form:

$$V = (15\, mn)^{4/3} \qquad (6)$$

which lends itself readily to plotting a series of inclined parallel lines on logarithmic scale paper so that for any delivery V, in cubic

feet per hour, so indicated on the horizontal scale, the vertical intersections with the inclined line, marked with the *depth* of the duct, indicates on the vertical scale the pertaining *width* of the duct.

The pertaining cross-sectional area is given at the time by ten times the value indicated by the intersection of the same vertical line with the inclined line marked 10 in.

Plotting an additional line according to equation (4), marked (v), its intersection with the same vertical line, indicates on the vertical scale the corresponding velocity of flow in feet per second.

The duct dimensions thus ascertained, may be slightly modified to suit conditions, if so desired or required. In that case the accepted dimensions determine, by equation (4) in the form:

$$v = \frac{144V}{3600 \times a} = \frac{0.04V}{a} \tag{7}$$

the actual velocity of flow for the stipulated volume of flow.

In either case the velocity of flow, thus determined, establishes for each section of the duct system the corresponding velocity head of the flow, and with that also the excess pressure necessary to overcome the resistance, prevailing in the duct, by equation (2). At the same time the resistance factor of each section represents the combined effect of *all* causes tending to retard the free flow of the air through the duct section and, as each part thereof can likewise be expressed as a proportionate part of the prevailing velocity head, analogously to equation (2), its aggregate for any duct section expressed in the form:

$$R = F + \zeta_1 + \zeta_2 + \zeta_3 + \text{———} \zeta_n = F + \Sigma\zeta \tag{8}$$

when: F = the resistance factor due to friction only, and

$\zeta_1, \zeta_2, \zeta_3, \text{———} \zeta_n$, = the resistance factors due to the various individual causes.

With the resistance factor R thus determined, the equation (2) can then be expressed in the more definite form:

$$h_t = h_v\ (F + \Sigma\zeta) \tag{9}$$

The friction factor F, representing that part of the resistance due to the friction of the air flowing through a duct of uniform cross section, is readily determined by the well established equation

$$F = \zeta L \frac{a}{p} \tag{10}$$

when: ζ = the coefficient of friction,

L = the length of the duct in feet,

p = the perimeter or circumference of the duct in inches,

a = the uniform cross sectional area of the duct in square inches.

When considering the importance of proper ventilation in schools, hospitals, public buildings, etc., and the multitude of publications on this subject in the current literature, the lack of authentic data from scientific researches as to the proper value of the coefficient of friction ζ, to be applied in a given case, is rather disappointing to

the designing engineer. It may be inferred here that it is more to the interest of the manufacturer to make his own researches and exploit the results without giving his competitors a share in the benefit derived. This is true only insofar as the expenses of such researches and possibly other sacrifices merit some reasonable compensation. On the other hand the withholding of such important information tends only to retard the proper development of the subject by the engineering profession in the interest of the general welfare.

A commendable exception to this more or less selfish attitude is presented by the experiments made by the U. S. Navy Department, from which the following conclusions were drawn, but with special reference to *round* ventilating ducts, viz.:

1. The coefficient of friction does not change with the velocity of the flow,
2. The coefficient of friction does not change with the size of the (pipe) duct, at least not up to sizes 3 or 4 sq. ft. in cross-sectional area,
3. The friction varies with the square of the mean velocity of the flow.
4. The coefficient of friction for pipe ducts of first class work and in the best condition is as low as 0.00008.
5. Comparatively small internal roughnesses, errors of shape or alignment, will increase the coefficient to 0.0001 or more.

Aside from the true merits of these experiments, it appears strange from the engineering standpoint, that the coefficient of friction should be presented in such an inconvenient and even incomplete form for general application. The true value of this coefficient should be expressed in the form: $0.00008 \times 2g = 0.00515$, in order to represent the friction head as a proportionate part of the velocity head and so conform with the best modern engineering practice. Furthermore, since the duct dimensions are usually given in inches, this coefficient must yet be multiplied by 12, so as to render it applicable in equation (10).

However, the first and second of the above stated conclusions do not coincide with those arrived at by the late Professor Rietschel from exhaustive tests, also made under Government auspices, with ducts of widely differing sizes and shapes and air velocities within wide ranges. These tests established the following facts:

1. In a duct of uniform cross-sectional area the coefficient of friction *decreases* with the *increase* of the velocity of flow.
2. The velocity of flow and other conditions being the same, the coefficient of friction *decreases* with the *increase* of the cross sectional area of the duct.

Whether the reduced friction in the larger ducts is due to the smaller ratio of the perimeter to the area of the duct (hydraulic radius) or to smaller internal friction of the air particles, is left open for conjecture. In any case the size and shape of the duct appears

to influence the produced frictional resistance to a considerable extent.

This assertion does not only appeal to logical reasoning, but is so proven by actual practice. In fact, the Rietschel coefficient has now been accepted as the most reliable, as testified to by the many attempts toward its application with so-called mean values. These proceedings are due to the rather complicated form in which this coefficient is presented, viz.:

$$\zeta = 0.0371 + \frac{0.0823}{v} + \frac{0.160}{p} + \frac{1.360}{pv} \quad (11)$$

when: $v =$ the velocity of flow in feet per second, and

$p =$ the perimeter or circumference of the duct in inches.

The effect of the velocity of flow and of the perimeter of the duct upon the produced friction, as represented by the pertaining value of the coefficient of friction according to equation (11), is corroborated by the results from observation, which varied from $\zeta = 0.042$ for high velocities in large ducts to $\zeta = 0.208$ for low velocities in small ducts.

The error of any attempts at applying mean values, as well as the lack of necessity for such proceeding will be demonstrated in the following considerations.

According to equation (10), the friction factor per linear foot of duct amounts to

$$f = \frac{p}{a}\left(0.0371 + \frac{0.0823}{v} + \frac{0.150}{p} + \frac{1.360}{pv}\right) \quad (12)$$

This rather complicated form, however, can be greatly simplified by expressing the equation (11) in the form:

$$\zeta = x + \frac{y}{p} \quad (13)$$

with: $$x = 0.0371 + \frac{0.0823}{v}$$

$$(14)$$

and $$y = 0.160 + \frac{1.360}{v}$$

in which case the equation (12), the friction factor f, from equation (12), can be represented in the modified form:

$$f = \frac{px + y}{a} \quad (15)$$

Furthermore, by expressing the dimensions of the rectangular duct m and n, in inches, and their ratio $\frac{m}{n} = z$, so that

$$p = 2\ (m + n) = 2n\ (1 + z) \text{ and } a = mn = n^2z \quad (16)$$

the friction factor f, per lineal foot of duct, can also be represented in the form:

$$f = \frac{1}{\sqrt{a}}\left(\frac{2(1+z)}{\sqrt{z}} + x\frac{y}{\sqrt{a}}\right) = (a)\,[(z)\,x + (a)\,y] \quad (17)$$

with: $\frac{1}{\sqrt{a}} = (a) =$ a function of the cross-sectional area,

$\frac{2(1+z)}{\sqrt{z}} = (z) =$ a function of the proportions of the duct, and

x and $y =$ functions of the velocity of flow according to equation (14).

Equation (17) shows clearly the wide range of the possible values of the friction factor with the prevailing conditions, and as such presents a strong argument in favor of a proper consideration of the conditions for which and under which the duct system is to be designed.

In order to more fully emphasize this assertion, the functions (a), (z), x and y are graphically represented by the curves so marked in Fig. 2. The curve of the function (a) has been plotted according to

$$(a) = \frac{1}{\sqrt{a}} = \frac{1}{0.2\sqrt{\frac{V}{v}}} \quad (18)$$

as a modification of

$$a = 0.04\,\frac{V}{v}$$

with V = the volume of flow in cubic feet per hour.

The curve of the function (z), plotted according to

$$(z) = \frac{2(1+z)}{\sqrt{z}}$$

shows clearly the unfavorable effect of the increased ratio z, corresponding to flat ducts.

The curves in Fig. 2 lead to still further considerations. When as usually, the volume of flow is given and the velocity of flow assumed, their ratio $\frac{V}{v}$, indicates by the curve (a) in Fig. 2, an increase of the value of the function (a) with an increase of the velocity of the flow v, while the corresponding values of the functions x and y decrease. However, as at the same time the velocity head of the flow increases with the *square* of the velocity, the favorable effect of the higher velocity upon the friction factor f, is greatly overbalanced. These facts present additional reasons to limit the allowable velocity of flow in the various sections of the duct system

of a ventilating or similar apparatus so as to assure a reasonably economic operation.

In addition to the friction of the air on the surfaces passed over in the ducts, there are other causes tending to retard the free flow of the air through the duct, such as changes of direction and velocity of flow and cross-sectional area; local obstructions, such as dampers,

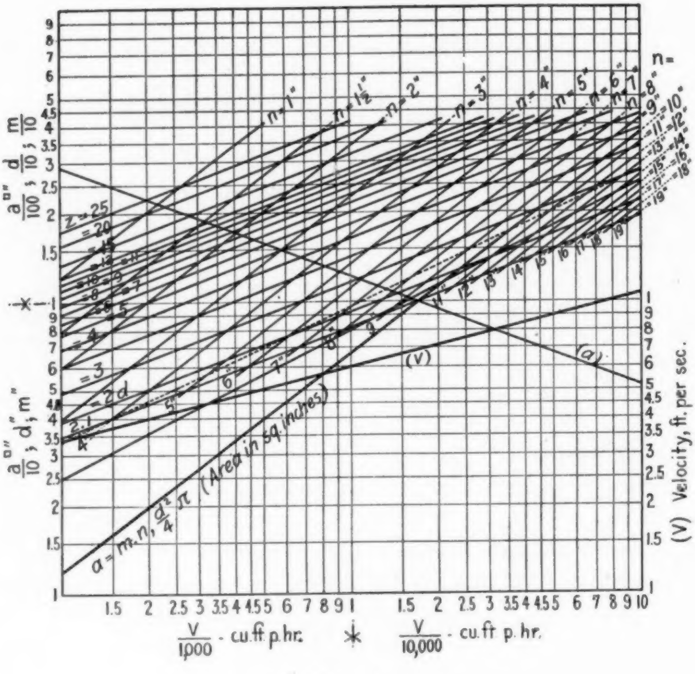


FIG. 1-A.

gratings, registers, etc., or special apparatus through which the air is forced to pass for special purposes, such as filters, heaters, etc. According to previous considerations, the resistance head produced by such an obstruction is in direct proportion to the square of the velocity of the flow, and therefore can be expressed as a proportionate part of the prevailing velocity head according to equation (2). The pertaining resistance factor representing this proportion, can, however, be determined to satisfaction only by experiment or practical experience. Fortunately, this has been done to some extent for the more or less standard appliances, and the results are readily obtainable from the current literature, especially Harding and Willard's "Mechanical Equipment of Buildings."

The importance of a proper consideration of the local obstructions as causes of resistance to the free flow of the air through a system of ducts, can be shown by a comparison of the friction factor due to such obstruction with that due to the friction in a straight length of duct of corresponding dimensions. This condition is readily represented by the relation:

$$\zeta = fl \tag{19}$$

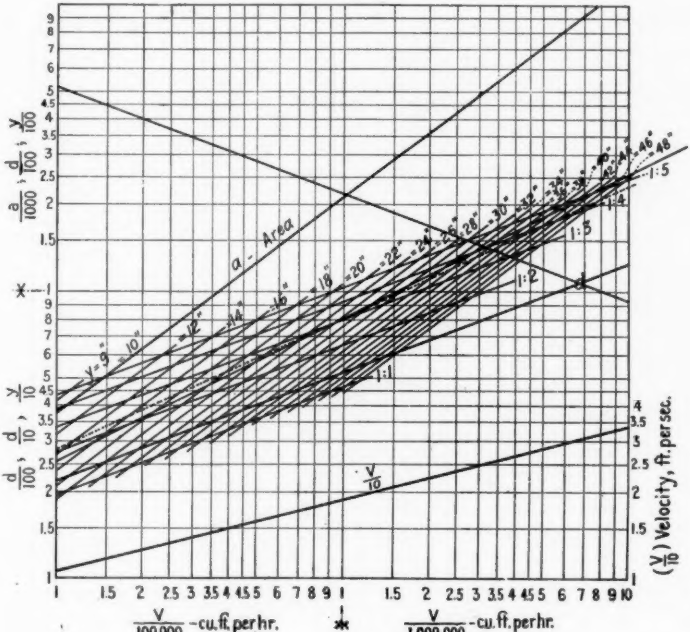


FIG. 1-B.

which, for $\zeta = 1$, determines by

$$l_f = \frac{l}{f} \tag{20}$$

the length of a straight duct of the corresponding dimensions, in which the produced friction head equals the prevailing velocity head. The length l_f, thus determined, may be termed the *friction length* of the duct and used to establish the *equivalent friction length* of any resistance factor ζ, in the form:

$$l_e = l_f \zeta \tag{21}$$

This procedure allows then the expression of equation (9) in the modified form:

$$h_r = h_v f L \tag{22}$$

with:

$$L = l + \Sigma\, l_e \tag{23}$$

representing the equivalent friction length of the duct section under consideration.

These considerations make it essential that sudden changes of cross-sectional areas are avoided as much as possible. This refers not only to branch connections with their lower volume capacity and corresponding lower velocity of flow, but mainly to such connections

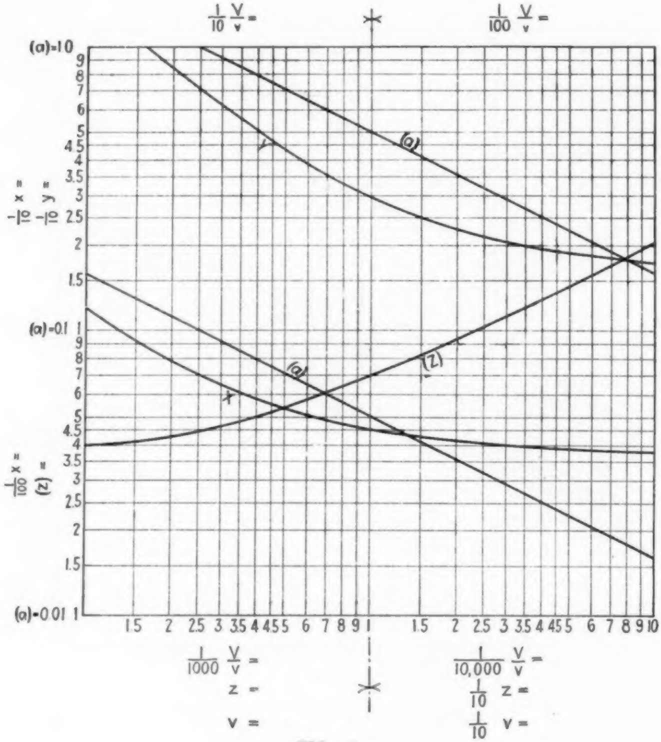


FIG. 2.

as are made to collecting, distributing and heater chambers, air filters, etc. In such cases a sudden and abrupt enlargement of a duct will cause a corresponding reduction of the velocity of the flow. This reduction of the velocity, however, is not uniform, the extent of the irregularity depending on the velocity of the entering air, the character of the duct enlargement and the presence of obstructions or special devices intended to prevent the formation of distinct or concentrated air current in the chambers, etc. Generally the loss of pressure due to sudden changes of duct areas can be expressed as a proportionate part of the velocity head prevailing in the supply duct by the resistance factor.

$$\zeta = 1 - \left(\frac{a_1}{a_2}\right)^2 \tag{24}$$

when: a_1 = area of the supply duct and
a_2 = area of the enlarged duct, chamber, etc. in the direction of the flow.

By making the change from a_1 to a_2 gradual, the pressure loss will be greatly reduced. In fact, according to tests made by Dr. Biel, the resulting pressure loss is practically negligible when the *contrac-*

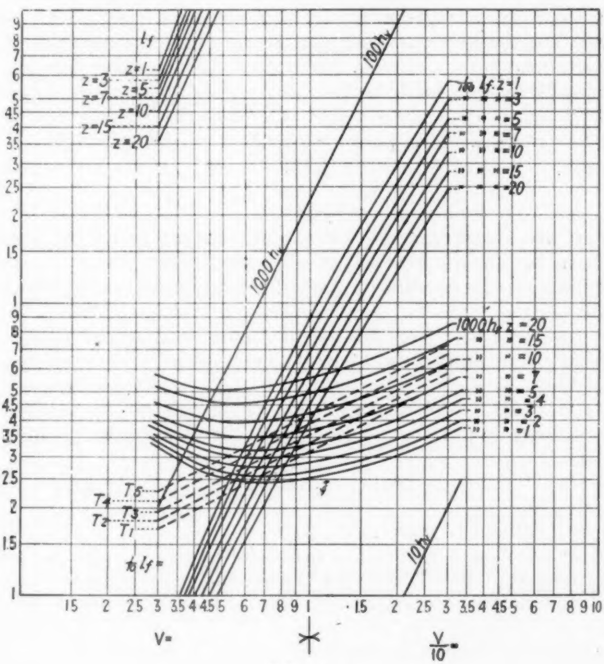


FIG. 3.

tion is made very gradual. On the other hand, when the cross-sectional area of the duct is gradually increased, the resulting pressure loss increases with the angle of divergence or the ratio of the increase of the area. For practical purposes it is suggested to limit the ratio of the area increase to 25 per cent, in which case the resulting pressure loss will be within 40 per cent of the difference of the velocity heads prevailing before and after the change. This condition can be expressed by the relation:

$$h_r = 0.4\ (h'_2 - h''_2) \tag{25}$$

The same considerations apply to changes of the *direction* of the flow. Where branches are taken from main trunk lines of ducts, the

angle of divergence should not exceed 45 deg. and should be smaller for branches receiving the air at high velocities than for such towards the ends of the trunk lines, where the velocities are greatly reduced. The last branch, as a rule, should lead off at an angle of 90 deg.

The exact values of the resistance factors to be applied in a given case, of course, can be determined only by a proper judgment of the prevailing conditions in connection with the data offered in the current engineering literature.

Accepting now the suggested inter-relation between volume and velocity of flow, as represented by equation (4) and its derivatives (5) and (6), the necessary calculations for the determination of the resistance head produced in a given case, become very simple, and may be still further facilitated by the use of a chart as shown in Fig. 3.

The line marked h_v, is plotted according to the equation

$$h_v = \frac{0.224}{1000} v^2 \qquad (26)$$

the generally accepted form for the determination of the velocity head in inches of water, so as to indicate on the vertical scale the velocity head corresponding to the velocity indicated on the horizontal scale.

The lower set of curves has been plotted so that any velocity of flow v, as determined from chart 1 for a given volume of flow V, the resistance head produced in a duct of the corresponding dimensions from chart 1 and a straight length of 1,000 ft. is represented by the ordinate of the curve marked with the ratio of the duct dimensions $\frac{m}{n} = z$ and so indicated on the vertical scale in inches as the height of a column of water.

The set of oblique curves has been plotted so that the pertaining friction length of the duct under these conditions is represented by ordinate of the curve marked with the ratio of the duct dimensions $\frac{m}{n} = z$, and so indicated on the vertical scale in feet.

For intermediate ratios z, the corresponding values of l_f and h_r are readily obtained by interpolation with sufficient accuracy for all practical purposes.

It remains now to illustrate the feasibility of the foregoing considerations for practical application by a concrete example, as well as the value of a systematic calculation and proper tabulation of the obtained results. The suggested proceedings will be further facilitated by a diagrammatic representation of the contemplated duct system in the manner shown in Fig. 4. It is suggested that such a diagram be prepared in all cases, aside from the actual drawing of the duct system, as it not only presents a convenient record of the proceedings, but greatly assists in any further proceedings due to

any contemplated or required changes of the duct system as originally laid out. The arrangement and execution of the appended table will be readily understood with the aid of the following suggested proceedings.

After establishing the general arrangement of the contemplated duct system on the drawing proper as to location and run, in due consideration of the local conditions and possible obstructions in the way, a corresponding diagram of the duct system is made. On this diagram are noted the required deliveries at the various terminals in cubic feet per hour and also the volume capacities of all sections of the duct system as determined according to the number and required deliveries of the terminals served from that point, together with a serial number.

For the next step the chart shown in Fig. 1 and the tabulated form, will be utilized. In column 1 are entered the serial numbers of the sections from the source to the last terminal of the longest trunk line, and in column 2, the pertaining volume capacities in cubic feet per hour.

In columns 3, 4, 5 and 6 are entered the data obtained direct from the chart, Fig. 1, by drawing a vertical line at the volume capacity of the duct section, so indicated on the horizontal scale, which, by its intersection with the various inclined and correspondingly marked lines, establishes at once the pertaining values of:

a = the area of the duct in square inches,
m and n = the dimensions of the rectangular duct in inches,
z = the corresponding ratio of these dimensions, and
v = velocity of flow in feet per second.

In columns 7, 8 and 9 are entered the data obtained from the chart Fig. 3 by drawing a vertical line at the velocity of flow, noted in column 6 and so indicated on the horizontal scale, which, by its intersection with the correspondingly marked curves, establishes at once the pertaining values of:

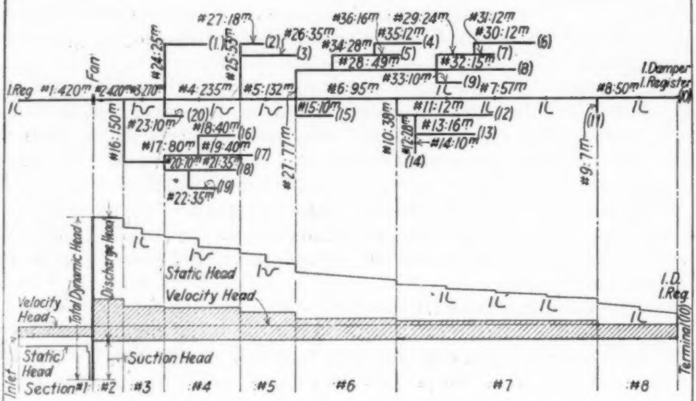
h_v = the velocity head of the flow in inches of water
h_r = the friction head produced in the duct, expressed in inches of water per 1,000 ft. of straight length, and
l_f = the friction length of the duct.

In column 10 are entered the lengths of the duct sections in feet, in column 11, the number, kind and type of all the local resistances contained in the section, and in column 12, the aggregate value of their resistance factors.

Thus far all data have been obtained direct from the drawing or from the charts without any calculations beyond the interpolations required for the determination of intermediate values from the charts.

Some additional calculations of a minor character, however, will be required in the following proceedings for the determination of the total resistance head produced in the apparatus.

The next step then consists of multiplying the value from column 10 with that from column 12, the result representing the equivalent



No. of Sec'n	Volume of Flow Cu ft Per Hr	Data from Chart Fig 1: Area A-Sq Ins	Dimensions m"xn"	Ratio Z	Veloc'y V Ft Per Sec	From Chart Fig 3: Veloc'y Head Hv-m/ins	Resist Head Hr-m/ins	Friction Length lf-Ft	From Dr'g: Length of Sec. L. Ft.	Number & Kind of Res.	Σζ	Data to be Calculated: Equiv't Length L. Ft.	Press. Drop m/ins.	Resist Head of Section m/ins.	Press. Available at Point
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		1. MAIN TRUNK LINE FROM FAN TO TERMINAL (10)													
2	420m	1110	30X37	1.233	15.20	52.00	.28	87	6	—	—	6	—	1.75	156.25
3	270 "	792	22X36	1.636	13.52	41.00	.28	72	8	1L	0.3	51	11.00	25.28	130.97
4	235 "	704	22X32	1.455	13.35	40.00	.28	70	15	1∽	0.6	57	1.00	16.96	114.01
5	182 "	594	22X27	1.227	12.30	34.00	.27	60	11	1∽	0.6	47	6.00	18.69	95.32.
6	95 "	357	17X21	1.235	10.50	25.00	.26	45	20	—	—	45	9.00	20.70	74.62
7	57 "	234	14X17	1.214	9.75	21.15	.26	40	40	3L	0.9	76	4.50	24.26	50.36
8	50 "	222	14X16	1.140	9.00	18.00	.26	35	16	1L 1D 1Reg	2.7	111	3.50	32.36	18.00
													Total Resistance:	140.00	
													Terminal Velocity Head:	18.00	
													Total Discharge Press.:	158.00	=0.158" W.G.
		2 SUCTION LINE TO FAN													
1	420m	2180	36X60	1.67	76	11.61	0.052	223	15	1Reg 1L	1.3	215	40.80	51.58	
													Velocity Head of Flow:	11.61	
													Total Suction Pressure:	63.19	
													Discharge Resistance:	140.00	
													Total Dynamic Pressure:	203.19	=0.203" W.G.
		3 BRANCH FROM SECTION 5 TO TERMINAL (6) PRESSURE AVAILABLE 95.32 m/ins													
27	77m	310	17X18	1.06	10.0	22.4	.25	40	18	2L	0.6	42	2.30	12.88	49.37
28	49m	220	13X17	1.31	8.9	18.0	.25	32	40	1L	0.3	50	1.10	13.70	35.67
29	24m	128	10X13	1.23	7.4	12.4	.25	24	15	2L	0.6	30	1.50	9.00	26.67
30	12m	77	8X10	1.25	6.0	8.8	.25	18	18	1R 1D 1L	2.7	67	1.12	17.87	8.80
		Surplus Pressure 95.32-63.25=32.07 to be throttled by Damper Near Sec. #5											Total Resistance:	53.45	
													Terminal Velocity Head:	8.80	
														62.25	=0.063" W.G.
		4 BRANCH FROM SECTION #2 TO TERMINAL (16) PRESSURE AVAILABLE: 156.25 m/ins													
16	150m	506	22X23	1.0	11.7	30.0	.26	47	16	2L	0.6	50	22.0	35.00	63.00
17	80m	324	18X18	1.0	10.0	22.4	.25	40	8	2L	0.6	32	7.6	15.60	47.40
18	40m	170	10X17	1.7	8.4	15.8	.25	30	10	1R 1D 2L	3.0	100	6.6	31.60	15.80
		Surplus Pressure of 156.25-98.00=58.25 to be throttled by Damper Near Sec. #2											Total Resistance:	82.20	
													Velocity Head of Flow:	15.80	
														98.00	=0.098" W.G.

FIG. 4.

actual length of the section, and the sum entered in column 13 as the equivalent friction length of the section. In column 14, is entered the pressure loss due to a reduction of the velocity of flow. This is obtained by subtracting the value of the velocity head from column 5, as prevailing in the section under consideration, from that prevailing in the preceding section and so noted in column 5, and the difference multiplied by 0.4.

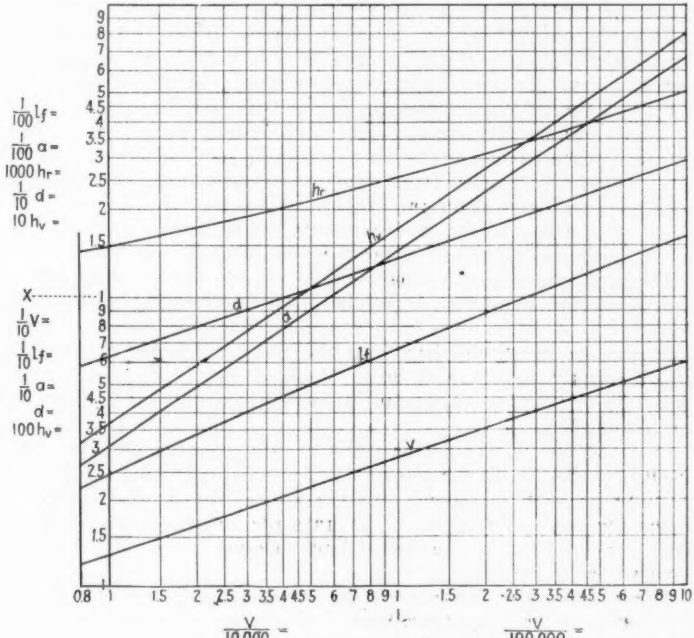


FIG. 5.

The last step in the proceedings consists now of multiplying the value from column 9 with that from column 13, adding to the result the value from column 14 and entering the sum in column 15.

Adding to the sum of the values in column 15 the velocity head prevailing at the last terminal of the trunk line under consideration, the total then represents the resistance head of this trunk line, expressed in mills or in units equal to 0.001 in. as the height of a column of water.

In the additional column 16 should be entered the resistance head available at these points for any branches diverging therefrom. This is essential, as it furnishes a basis for the proper consideration of the existing conditions in order to obtain the necessary proportions of the branch duct for the required distribution of the air.

In table B are entered the corresponding data for the sections comprising the branch marked B. The other branches are to be treated in the same manner.

Beyond these the designer will need no further suggestions except that the same method may be applied for other conditions, where higher velocities of flow are desired or even required, as for ship ventilation and similar cases.

A suggestion in this direction is offered in chart Fig. 5. which is plotted on the basis of $v = 0.6\ V^{1/6}$, and the use of round ducts.

Thus for any delivery V, in cubic feet per hour, as indicated on the bottom scale, a vertical line will at once indicate by its intersection with the corresponding curves, so marked, the pertaining

v = the velocity of flow, in feet per second,
l_f = the friction length of the duct, in feet,
d = the diameter of the duct in inches,
h_r = the resistance head produced in the duct, expressed in inches of water per 1,000 ft. of length.
a = the area of the duct in square inches, and
h_v = the velocity head of the flow, in inches of water.

The application of this chart will be exactly the same as that of the charts, Fig. 1 and Fig. 3, and therefore needs no further explanation.

It may be mentioned here that the results obtained from chart Fig. 4 comply closely with those obtained with very satisfactorily operating ventilating apparatus in battle ships and ocean liners of the better class.

In conclusion it may not be amiss to refer to a comparison of the results obtained with the use of the Rietschel coefficient of friction to those probably obtained with the use of the Taylor coefficient under the same conditions. The probable results upon the latter basis are indicated by the dotted lines marked T_1, T_2, T_3, T_4, with recognition of the ratio z.

These lines show conclusively the error incurred, not only by the application of the Taylor coefficient, but also by the neglect to recognize the effect of the ratio z, and so corroborate theoretically the practical experience.

DISCUSSION

FRED R. STILL: There is one thing omitted from this paper more important than the determination of the friction of the straight pipe, that is, the elbows, which the author says nothing about. The friction of the ordinary ventilating system is very low; if you eliminate all the elbows. There is not much that is particularly new in this paper, even to the diagrams, which are very similar to what are very commonly used and have been in use for a long time.

ARTHUR S. ARMAGNAC: Perhaps it has been noted by the members that the author's method approximates that of Konrad Meier in his work on "Mechanics of Heating and Ventilation." This method has been published for some time and, of course, was known to those whose methods the author criticises. It may be of interest to state that the methods in question are those used by the New York City Dept. of Education, the Supervising Architect's Office of the Treasury Department, and engineering firms in New York and elsewhere. The question might be asked: "Why do they continue to use these methods in view of possibly more accurate data?" The point made by Mr. Still is one answer to that question. The answer would seem to be in the practical difficulties involved in commercial practice.

The author might have gone a step further than he did and taken into account the corrections to the volume for leakage in transit, as well as the corrections to the total pressure for higher or lower temperatures of the air to be moved. Mr. Meier's work gives consideration to the equalization of the resistances for the desired volumes and also gives corrections for deformed and poorly-built sheet-iron ducts, for masonry ducts and for duct work of different shapes. Various factors of resistance are also given so that it would not be necessary, as the author suggests, to refer to current engineering literature for these factors.

The problem of sizing ducts may be approached along another line since in most instances the velocities, especially at outlets, should be kept within certain limits for various practical considerations, and the total pressure required for moving the air are, to an extent, governed by these velocities. To secure a fairly equable discharge through the full area of the register supplied from a vertical flue, the velocity in this flue should not exceed that through the outlet by more than 50 per cent. The laws regulating the ventilation of school buildings also require the supply and removal of large volumes of air in a short space of time, with a velocity of air entering and leaving the room low enough to avoid noise in the registers and drafts through the room. In the case of a manufactory, on the other hand, a high velocity is often necessary to force the air 100 ft. to 200 ft. from the outlet through the open room. Frictional resistances are increased with high velocities but as the fan in such a case usually operates at a higher speed, the proportional losses are not excessive,

while the rapidity of the movement reduces the time during which the moving air within the duct may part with its heat.

In considering elaborate systems of duct design, it must be remembered that with the ever-changing cost of installation and operation, it is difficult to fix, as the author states, "a limit to the allowable velocity head beyond which the advantage gained with small ducts as to the cost of installation is outweighed by the disadvantages of the high operating expense of producing necessarily high pressures corresponding to the high velocities in the small ducts." It involves the consideration of the cost of power, interest and depreciation. It may be interesting to recall that a formula was worked out in a paper presented before the Society in 1913, covering these points.

In further reference to this point, Sturtevant's "Heating and Ventilation" states:

> "It would seem advisable to move the air at a low velocity, but the size of the ducts will limit the permissible velocity of flow as the increased cost of large ducts will rapidly exceed the saving in power obtained with low velocity. Although the loss in power for increased velocity increases with the cube of the velocity, the common practice of utilizing exhaust steam in the heater when the fan is driven by a steam engine makes economy of power to drive the fan a consideration of secondary importance."

In any discussion of extreme accuracy in duct design, actual practice brings the engineer face to face with the fact that in many cases the architects will not allow sufficient space to accommodate ducts of desirable size, nor do the results obtained by ideal duct sizes always justify the consequent increase in the cost of the building.

Coming to the specific points raised by the author, in reply to the first point it may be stated that Method No. 1, described in the data sheets under discussion, contains the direction to "size the ducts on the basis of the area required to pass the given quantity of air at a given velocity." Incidentally, Method No. 5 provides for a temperature drop in the duct, an item which the author does not consider in his paper.

The fourth point raised by the author is true so far as the actual produced resistance head is determined by calculation. The head, however, is certain to vary from that produced by calculation, irrespective of the method followed, or it may vary due to certain structural conditions causing modifications from the plans. In practice, it is customary to assume a resistance head based on experience with large and small ventilating systems in various types and classes of buildings.

How necessary it is to make certain assumptions is illustrated in the author's paper in connection with his formula No. 4 which, he states, is a formula derived from experience. The author also states: "The exact values of the resistance factors to be applied in a given case, of course, can be determined only by a proper judgment of the prevailing conditions in connection with the data offered in the current engineering literature." This statement shows

the difficulty with any theoretical method of sizing ducts, since the factors of resistance, such as bends, reductions, etc., cannot be accurately known, while new shapes are constantly being encountered.

Of course, both the Society and all responsible engineering journals are always interested in obtaining accurate scientific data, whether based on a practical or theoretical basis; but the fact remains that we have practical conditions to contend with and, after all, the most delicately-balanced systems have to be adjusted to meet the situation as it develops.

A Member: In 1910 a paper was written by one of our engineers, Mr. Thomas N. Fitch, giving suggestions for various materials, such as brick, stone, cement, etc. It was prepared particularly for mining engineers and covers this entire matter. In heating work it is necessary particularly where there is high velocity, to reduce the noise. Every wind cannot be driven as it is heard outside, and that is almost always precluded from consideration. Years ago, I undertook to figure it on a commercial basis, to find out the best all-around efficient velocity necessary to drive air, and it is about 2,400 ft., when considering the cost of installation, operation, depreciation, and general efficiency.

A Member: Is the maximum velocity in the main duct 2,400 ft.?

A Member: If there is a low velocity the equipment is larger. Therefore more is spent for the plant than is necessary. If 2,400 ft. are reached, the maximum velocity is obtained. Beyond that, the cost of moving the air exceeds the results received commercially.

A Member: Is that velocity recommended for public buildings?

A Member: No.

No. 575

THE RELATION OF THE DEATH RATE TO THE WET BULB TEMPERATURE

A Review of Dr. Huntington's Interpretation of the Death Rate by Climographs

By E. Vernon Hill, Chicago, Ill. (Member)

and

J. J. Aeberly[1]. Chicago, Ill. (Non-Member)

IN the first number of *Modern Medicine,* May, 1919, appears an article by Dr. Huntington, in which the average death rate for certain periods is plotted against corresponding average temperatures and humidities prevailing at the time and the resulting climographs, as he has called them, used in an analysis of the relation of climatic conditions to the death rate. The subject is one of deep interest and also of great importance, and the results obtained by the analysis of these climographs bear out the assertion made by Dr. Gottfried Koehler, Assistant Commissioner of Health of Chicago, as well as other students of the subject, that the sum total of activities of health departments and other health conserving agencies is negligible as compared with the effect of meteorological conditions that prevail during the period.

Dr. Huntington is entitled to a large measure of credit for compiling this enormous amount of valuable data and presenting it analytically in its relation to morbidity statistics. Investigators who are interested in this line of work can appreciate the difficulties encountered. It is a hard matter to obtain anything like complete data on humidity, wind velocities, etc., in the United States alone, to say nothing of foreign countries. Until the present year, the available observations of the United States Weather Bureau on the relative humidity were confined to readings taken in the morning and evening. During the present year, they have added a reading taken at mid-day. Needless to say, morning and evening readings alone do not always give a fair average for the 24 hours in question, al-

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Presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

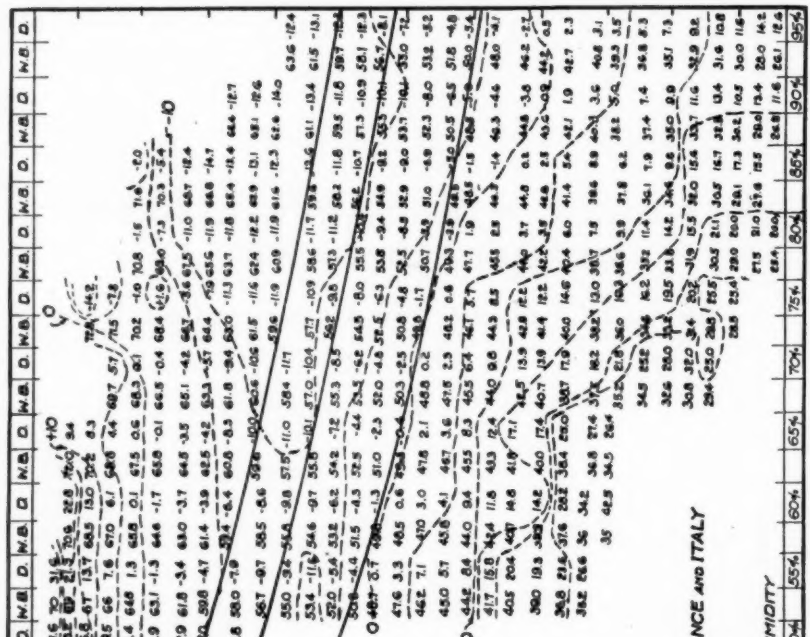

FIG. 1. UNSMOOTHED CLIMOGRAPH OF FRANCE AND ITALY.

though the more or less constant increase during the night is counterbalanced to an extent by a corresponding drop at mid-day.

Published reports on temperature observations also have been confined to maximum, minimum and mean and, while the mean is usually close to the average of the 24 hours, this is not necessarily the case. The work undertaken by Dr. Huntington brings out the desirability of having more complete meteorological data and the Committee of our Society appointed some time ago to confer with the Weather Bureau on this subject should have in mind the compilation of morbidity statistics as well as the adaptation of the Weather Bureau reports in ordinary ventilation and air conditioning work.

Fig. 1 is reproduced from Dr. Huntington's article and is typical of the charts he presents. It is an unsmoothed climograph of France and Italy covering a period from 1899 to 1913 and represents 3,700,000 deaths. The chart is plotted with the dry bulb temperature as ordinates and the relative humidity as abscissae. The average of all deaths occurring under certain definite conditions of temperature and humidity is determined, and the variation of this from the normal death rate plotted on the chart as the percentage of deviation. For example, in Fig. 1, at 50 deg. dry bulb and at a humidity of 85 per cent, the average death rate is minus 1.5. This figure means that the average of deaths under these conditions is minus 1.5, or 1.5 per cent below the normal. Pursuing the subject further, the points of equal death rate are connected by transverse lines forming zones or isopracts representing areas covering definite conditions of temperature and humidity where the death rate is uniform. That is, the death rate is uniform for any line, but varies as we move from one line to another. This chart is one of six presented in the article referred to, which cover a wide range of observations, and deal with various conditions. It is fairly typical as illustrating the method and the result obtained by that method. In examining this chart, we find that the lines of constant death rate on the lower half of the chart, slope quite uniformly downward from left to right and the death rate decreases as we pass upward along the chart until a point is reached at about 65 deg. dry bulb, where the slope of the line changes, passing upward to the right instead of downward. This gives an irregular area between 60 to 95 per cent relative humidity and between 55 and 75 deg. dry bulb, in which all the values are minus and all less than minus 10. This means that in the area referred to, the death rate varies from minus 10 to minus 14 but it is always at least 10 per cent below the normal and with respect to temperature and humidity it is clear that the ideal condition must lie within this area. Dr. Huntington points out that this ideal condition is a temperature of 64 deg. fahr., and the relative humidity of 80 per cent. By referring to a psychrometric chart (see Fig. 4), it will be observed that the temperature of 64 and a relative humidity of 80 per cent gives a wet bulb temperature of approximately 60 deg. Dr. Huntington concludes

Fig. 1. Unsmoothed Climograph of France and Italy.

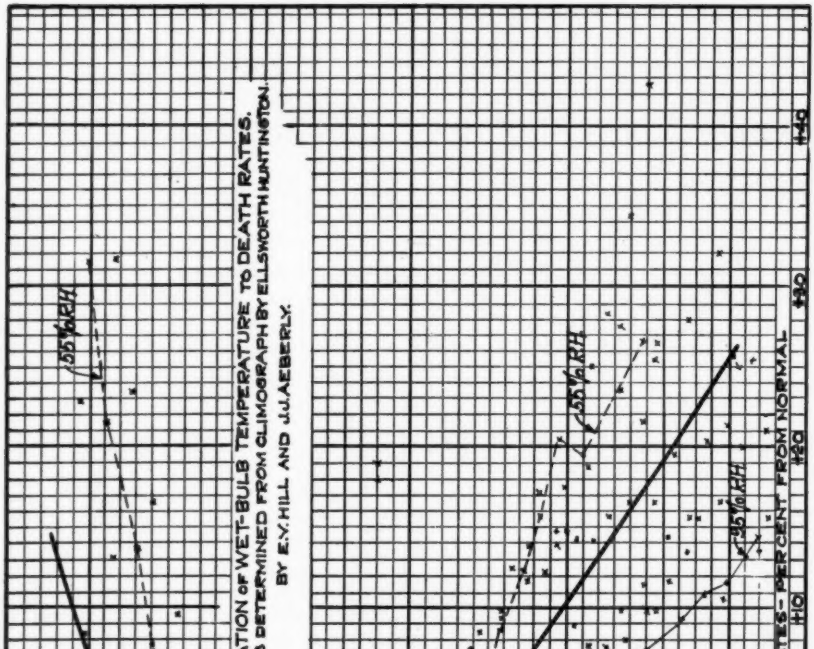

FIG. 2. RELATION OF WET BULB TEMPERATURE TO DEATH RATE AS DETERMINED BY THE AUTHORS FROM CLIMOGRAPH BY ELLSWORTH HUNTINGTON.

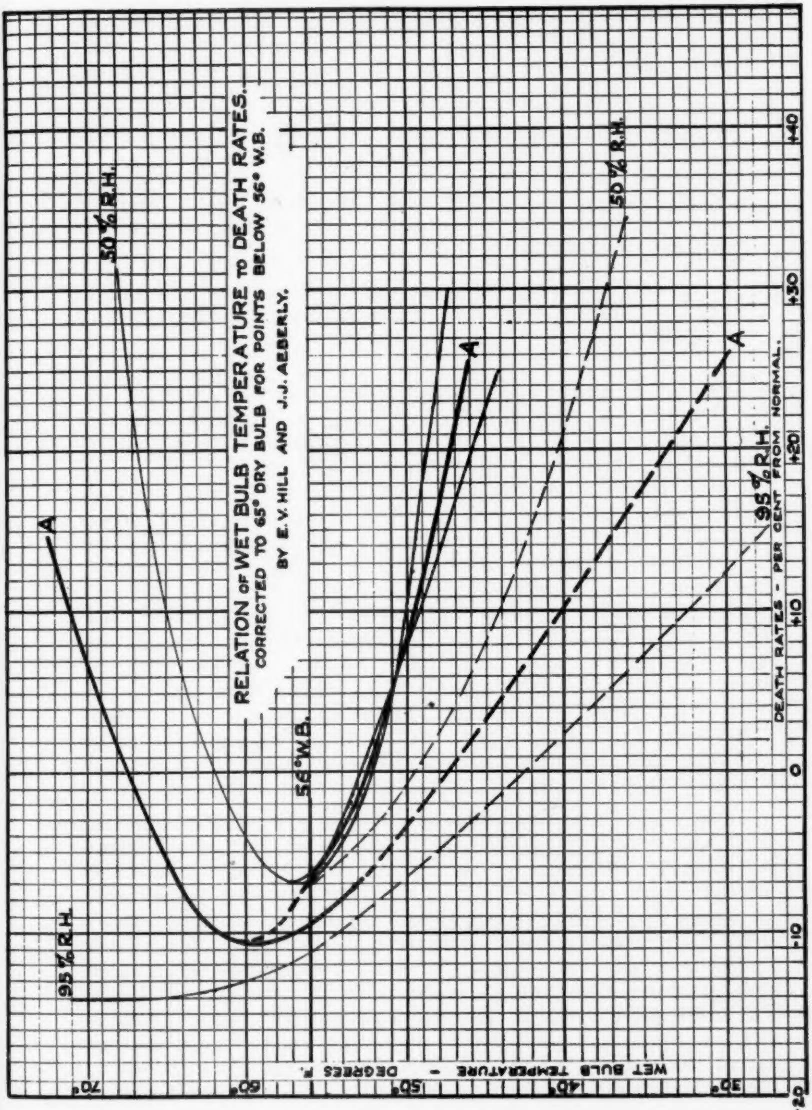

FIG. 3. RELATION OF WET BULB TEMPERATURE TO DEATH RATE, CORRECTED TO 65 DEG. DRY BULB FOR POINTS BELOW 56 DEG. WET BULB.

in general, that climatic conditions have a very important influence on the death rate and that the results of even daily variations can be clearly ascertained. He also sets forth three conclusions which are as follows:

1. Fairly moist weather is almost invariably more healthful than dry weather of the same temperature;

2. Cold waves, unless of extraordinary severity, are beneficial to health while a rising temperature, even in the winter, is harmful. He distinguishes carefully between a drop in temperature and the continuance of low temperature;

3. A variable climate is in general, much more healthful than a uniform climate, even though the latter has an almost ideal temperature.

The writers have contended for many years past, that the wet bulb temperature is the determining factor in comfort, and that considerable variations in both the dry bulb temperature and the relative humidity are allowable and possibly desirable, provided the wet bulb temperature remains constant. The desirable wet bulb temperature for still air, we have experimentally determined as very nearly 56 deg. during the heating season. In the summer months, the desirable wet bulb rises to about 60 deg. This is due to the fact that the amount of clothing worn is less and greater facility is offered for the heat generated by the human body to escape. Furthermore, the quantity of food consumed is less, particularly the proteids and fats, which have a high calorific value. As the total heat in the air is constant if the wet bulb is constant, it clearly follows that the wet bulb is the factor in determining comfort and possibly health as well. It has never been demonstrated that moderate variations in the dry bulb or in the relative humidity directly affect health or comfort, unless there is also a change in temperature of the wet bulb.

If the reader is willing to admit the truth of the foregoing, it is clear that we can convert the two factors, temperature and humidity, into a single factor, namely, the wet bulb, and plotting the morbidity statistics in Dr. Huntington's chart against the wet bulb temperature, gives us a much clearer conception of the relation existing between climatic conditions and the death rate. In this way only can we obtain the proper viewpoint of the relation existing between health and heat dissipation from the body. This has been done in Fig. 2. The points plotted in this chart are death rates at various temperatures and humidities converted to the proper wet bulb, and the average of these points is shown by the heavy curved line. It will be observed that at a wet bulb of 30 deg., the average death rate as shown by the curved line is 25 per cent above normal and that as the wet bulb increases, the death rate decreases, until the approach of the ideal of 60, where the death rate is 10.6 per cent below the normal. As we go above 60 wet bulb, the curve reverses and the death rate in-

creases, until at the end of the curve at a wet bulb of 72½, the death rate has increased to 14½ per cent above normal. This brings out clearly, the important influence of the wet bulb temperature on the death rate and also presents a strong argument in support of the statement that the ideal wet bulb in the summer months is about 60 deg.

Examining this chart further, we note that there is a fairly uniform distribution of the death rate points below a wet bulb of 56 and that they converge at 56. This covers a small area on the chart. As we go above 56, it is to be noted that the points diverge

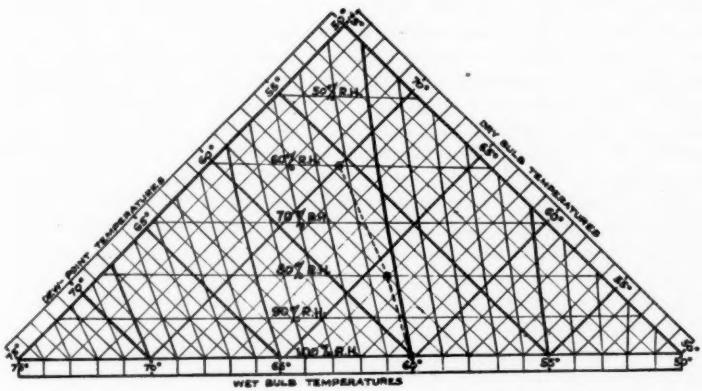

FIG. 4. GRAPHICAL COMPARISON OF WET BULB TEMPERATURE WITH ELLSWORTH HUNTINGTON'S CONCLUSIONS.

The Ideal Temperature and Humidity is 64 Deg. and 80 Per Cent With a Variation From 70 Deg. and 60 Per Cent to 60 Deg. and 100 Per Cent.

rapidly and that the average curve makes one think that the curve itself has very little significance. Examining this matter further, we find, by referring to Fig. 1, that the area bounded by the minus 10 death rate line, namely, the area of ideal conditions, represents the divergence of the points immediately above 56 on Fig. 2. In other words, we have lines of equal death rate running parallel to the lines of wet bulb temperature on Fig. 1 below 56 wet bulb. Above this point the lines of equal death rate slope upward, forming the isopracts referred to by Dr. Huntington that always converge to the left. We must answer a query at this point: If the wet bulb temperature is the determining factor in the death rate in so far as this chart is concerned, why do the lines of equal death rate slope downward below 56 bulb and upward above 56? We believe it is due to the fact that the chart is in reality, two charts instead of one. Below 56 wet bulb is the indoor condition and above 56 wet bulb is the outdoor condition. In other words, the chart was compiled from Weather

Bureau reports of outdoor temperatures and humidities. Below a wet bulb of 56, life is carried on indoors. Windows and doors are closed, and artificial heat is required. The effects of variations in the weather conditions are certainly those of the population who are living indoors, probably confined to their beds. Under these conditions, as artificial heat is required, the temperatures and humidities shown on the chart are not the temperatures under which deaths occur. It would be necessary, therefore, to raise the temperature to say, 65 deg. on all points on the chart below a wet bulb of 56. This would then give a much lower relative humidity and a higher wet bulb.

It is to be observed in Fig. 1 that the lowest point with respect to relative humidity is 50 per cent. It is seldom during the heating season that the air reaches a relative humidity as high as this indoors, so we must replot that part of the chart below 56 wet bulb by increasing the temperature to represent conditions as they actually exist. This will throw practically all of the deaths in this part of the chart into a condition where the greater part of the death rate will be in a region below 50 per cent relative humidity. This has been done in Fig. 3 where the temperatures representing all deaths below 56 wet bulb have been raised to 65 deg. We find by this method of analysis, that the convergence of the isopracts referred to by Dr. Huntington disappears and that all lines of equal death rate have the same general direction and considerable uniformity terminating in a line at 65 deg. and bearing a distinct relation to the wet bulb temperature.

Now, correcting the chart shown in Fig. 2 by increasing the dry bulb temperature from the outdoor condition to what it would be indoors with a temperature of 65 deg., gives a uniform wet bulb curve closely approximating a hyperbola with the apex at a wet bulb of about 60 deg. It will be noted that after this correction is made, the spread of the death rate points is materially lessened where indoor conditions are represented. This is to be expected, as we have to deal with only one factor, namely, wet bulb temperature, having eliminated the many other variables such as air motion, etc., which influence that part of the curve above 56 representing outdoor conditions.

The reader may question our right to determine the humidity indoors by warming the outdoor air to a temperature of 65 deg., and it is probably true that this will not always represent the indoor humidity; nevertheless, while other factors may have a bearing on the result, it is reasonable to assume that this method comes much closer to the actual conditions that prevail than by dealing with outdoor temperatures and humidities alone.

The ideal temperature and humidity arrived at by Dr. Huntington, namely, 64 deg. and 80 per cent, correspond with our experimental data on this subject, although we believe it should be expressed as wet bulb rather than as a temperature and humidity standard. Dr. Huntington's conclusions with regard to the variability are also logical and, we feel, of great value in arriving at a

correct understanding of this important subject. It is probably true, however, that this variation should be in the temperature and humidity as the writers have pointed out on previous occasions, provided such variations maintained the constant desirable wet bulb. In the ideal conditions mentioned by Dr. Huntington, we have a temperature range of from 60 to 70 deg. with a corresponding relative humidity range of from nearly saturation, where he speaks of dew falling, to a relative humidity of 60 per cent. This approaches closely a wet bulb range of 60 deg. which is the correct wet bulb for summer weather.

Dr. Huntington states that fairly moist weather is almost invariably more healthful than dry weather. This, we believe, is only true when the increased moisture brings the wet bulb nearer the ideal. It could not well be otherwise, as his next conclusion, "cold waves are distinctly beneficial" means the reverse. A cold wave in winter necessarily means a lowering of the humidity indoors and a lowering of humidity would not, according to Dr. Huntington's charts, reduce the death rate. It is probably true that the cold waves, considered as variations, are beneficial, but only as such. This, we believe, is clearly set forth in the article under consideration.

Dr. Huntington's contribution to this subject recalls to mind, probably the first chart of this nature, Professor J. W. Shepherd's Zone of Comfort. This zone as determined by Professor Shepherd is in reality, Huntington's isopract of lowest death rate, and the *line of comfort* through the center of Shepherd's Zone is 56 wet bulb.

No. 576

THE RELATION OF WET BULB TEMPERATURE TO HEALTH

By O. W. Armspach, Pittsburgh, Pa.

Member

THE facts set forth in this article would lead to the conclusion that there is some definite relation between wet bulb temperature and the health of the community. The results have been obtained by comparing the number of deaths in representative districts throughout the United States with the corresponding weather conditions recorded by the United States Weather Bureau. Although the general effects of the various weather conditions are fairly well recognized, the importance of these effects and their definite relation to health is not so well understood. In a study of this kind minor factors must be overlooked and too much importance should not be attached to sudden or inconsistent fluctuations in the number of deaths for certain individual months. These inconsistencies, however, are almost entirely eliminated by extending the study to cover a period of years. Favorable weather conditions are shown to be conducive to good health but they do not necessarily secure it.

A comparison of approximately 3,612,000 deaths with the corresponding weather conditions resulted in the following conclusions:

1. During the non-heating season physical health, to a large extent depends upon the wet bulb temperature of the air outdoors.

2. During the heating season, when no artificial means of humidifying the air is used, physical health depends upon the dew point temperature outdoors, the most favorable dew point being the one that will result in the highest wet bulb temperature indoors.

3. The ideal wet bulb temperature to be maintained indoors lies between 57 and 61 deg. The most favorable wet bulb temperature is practically constant for all the climates studied irrespective of the dry bulb temperature or humidity.

Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

THE METHOD OF COMPUTING RESULTS

To determine the exact relation of the wet bulb temperature to health, an examination was made of approximately 3,612,000 deaths in 27 cities representing the various climates throughout the United States. The month was used as the unit for the comparison of the mortality statistics with the weather conditions. The first step was to tabulate the actual deaths for the 27 cities by months for the years, 1900 to 1917 inclusive. A correction was made for short months to place them all on a 31 day basis. The next step concerns the normal number of deaths for each month during the years studied. By normal, is meant the deaths that would have occurred if there had been no increase in population and the sanitary conditions had

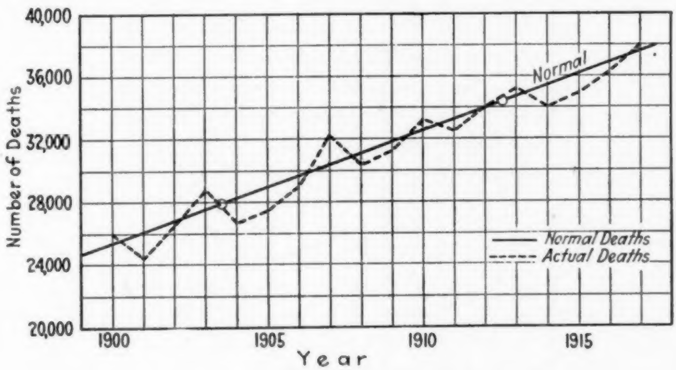

FIG. 1. YEARLY AND NORMAL DEATHS IN CHICAGO.

remained the same. To determine the normal curve, the total number of deaths for each year was plotted as is shown by the dash line in Fig. 1. An average of the first nine years was then obtained and the point was plotted in June, 1904. This point is the center of the first nine-year period and it is indicated in the figure by a small circle. The same was done for the last nine-year period. A straight line representing the normal deaths was then drawn through the two points. In like manner, a curve was constructed for each city studied. In most cases it was a straight line; in a few instances, however, it was necessary to divide the 18 years into more than two periods, and the normal was constructed in the form of a curved line.

It will be noted that the normal curve is based upon the actual number of deaths rather than the deaths per 1,000 population. Since the population for the nine years preceding an official census is based on the assumption that the annual increase in population is equal to 1/10 of the decennial increase, it is believed that the normal

curve will respond to an increase or decrease in population with more accuracy than if it were obtained with an assumed population as its basis. The curve will rise as the population increases and fall as the sanitary conditions are improved.

Fig. 1 is the curve for Chicago. The dash line shows the actual number of deaths by years and the full line shows the normal number. Any point on the curve gives the instantaneous yearly deaths for the month and the effects of population, sanitary conditions, and minor factors are eliminated. In this way the point for

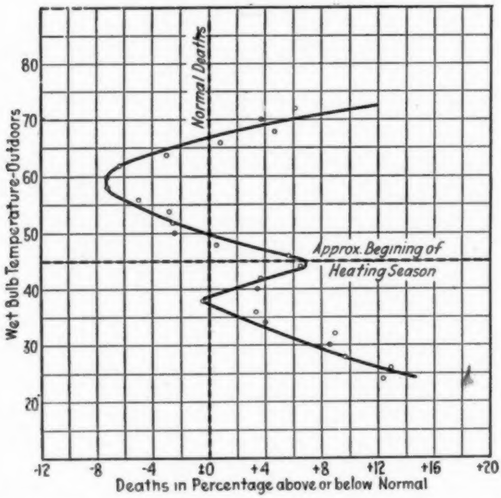

FIG. 2. RELATION OF WET BULB TEMPERATURE TO HEALTH, PLOTTED FROM A STUDY OF 3,612,000 DEATHS.

each month for all cities was taken from the curve and the normal deaths tabulated for the months from January, 1900, to December, 1917. This list was then compared with the list of actual deaths, and the percentage by which the actual varied above or below the normal was found for all months. If above, it was marked plus, and if below, minus.

For example, in Chicago, during July, 1916, the actual number of deaths was 3436 and the normal number was 3057, so that the result for this month was 12.4 per cent above normal. Table 1 is the complete list for Chicago. When the percentages above or below normal were thus computed for all cities studied, they were grouped according to their corresponding wet bulb temperatures. That is, all months having a wet bulb temperature of 24 deg. were placed in a group, all having a temperature of 25 deg. in another group, and so on through the list. For instance, Chicago had five

months when the average wet bulb temperature for the month was 24 deg., Denver had six, Salt Lake City had one, etc. The average mortality for the five months in Chicago was +27.28, in Denver +16.32, and in Salt Lake City +17.8. In this way the average mortality was computed for each city represented in the group. This resulted in a record of the percentage of deaths above or below normal for all wet bulb temperatures for a period of 18 years. An average mortality was now computed for all the months in the same group. A correction for population was made, however, before

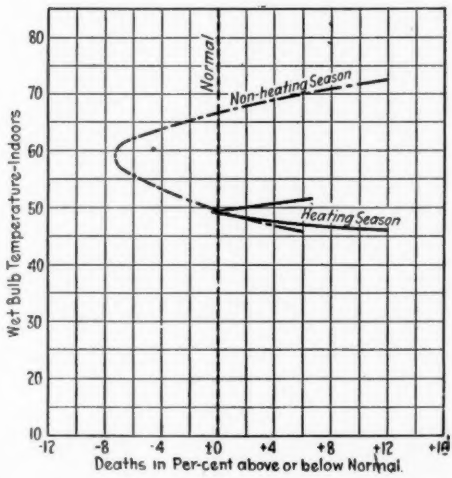

FIG. 3. HEATING SEASON CURVE CORRECTED FOR INDOOR CONDITIONS.

the final average was determined. A city having a population of 10,000 would evidently be given less weight than one having a population of 600,000. Therefore a weight consistent with the number of inhabitants was given each city before the final average for any particular wet bulb temperature was determined.

Table 2 illustrates the method of determining the average mortality for the different temperatures. Column 2 is the average for each city in the group. Column 3 is the weight given the city. The average for the entire group is +17.9 per cent.

The foregoing procedure resulted in a table of average departures of deaths from normal with the corresponding wet bulb temperatures. The departures for three consecutive temperatures were averaged and the points plotted in Fig. 2. The points from which the curve was plotted are given in Table 3.

TABLE 1. DEPARTURE OF DEATHS FROM NORMAL BY MONTHS FOR CHICAGO

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1900	+19.3	+11.0	+36.0	+20.7	+ 8.8	-11.9	+ 2.0	+ 1.6	- 5.7	-15.3	-15.2	+ 4.0
1901	+ 7.0	+ 0.5	- 6.2	+ 3.0	- 6.0	-12.9	+ 4.0	+ 3.0	- 3.0	-16.3	- 9.7	- 4.5
1902	+ 2.0	+13.4	+ 6.5	+ 6.5	- 2.2	-12.3	+ 4.0	+ 7.2	- 5.2	-12.0	- 5.9	+15.5
1903	+16.5	+26.3	+16.8	+19.5	+16.5	- 5.4	+ 2.0	- 3.0	- 5.7	-11.8	- 6.7	+27.2
1904	+ 5.0	+28.0	+12.0	+14.5	- 7.1	-23.1	-14.5	-10.8	-12.8	-16.7	-15.0	+ 2.5
1905	+ 2.5	+16.4	+ 9.0	+ 1.5	- 7.8	-13.3	- 3.7	+ 2.6	- 7.5	-11.0	-10.4	- 4.2
1906	+ 2.1	+ 1.5	+ 4.0	+16.0	+ 2.5	-16.8	- 8.6	+ 1.3	- 2.0	- 6.4	+ 1.6	+ 8.6
1907	+23.6	+32.0	+22.0	+21.6	+20.3	- 4.0	- 9.5	+13.0	+ 3.3	-11.2	- 7.4	+ 3.2
1908	+22.8	+19.4	+11.5	+ 2.7	- 5.6	-17.9	- 8.0	+ 4.2	- 7.9	- 9.2	- 6.0	- 5.8
1909	+ 6.6	+ 4.1	+15.3	+12.1	+ 1.7	-12.2	-14.8	+ 2.2	+ 0.3	- 2.3	- 4.8	+ 2.7
1910	+ 9.2	+15.0	+22.8	+ 9.9	+ 6.6	- 1.2	+ 2.5	+ 1.4	- 5.0	-10.4	+ 0.6	+ 6.8
1911	+19.1	+ 9.2	+13.6	+ 8.9	+ 4.4	-14.1	+ 4.1	- 7.9	-12.9	-13.8	- 4.9	- 1.3
1912	+18.8	+21.3	+11.0	+ 8.0	- 2.7	-10.4	- 7.9	- 4.5	- 5.9	- 5.7	- 5.6	+13.8
1913	+16.7	+25.9	+24.5	+13.9	+ 2.1	+ 4.5	- 5.1	- 2.8	- 2.1	-12.4	- 6.8	- 4.4
1914	+ 5.4	+19.6	+23.5	+16.6	+ 2.4	-15.7	- 9.1	- 7.9	-14.9	-19.4	-12.1	- 6.8
1915	- 7.8	+14.0	+18.9	+ 9.3	- 9.6	-16.8	+ 7.3	-13.2	-15.7	-13.8	-15.1	+23.9
1916	+27.1	+13.2	+12.7	+ 0.5	- 4.3	-20.9	+12.4	- 1.7	- 8.5	-14.5	- 8.5	+ 0.75
1917	+26.6	+24.8	+25.0	+21.5	+13.0	- 6.5	-13.0	-10.1	- 7.5	- 7.4	-11.0	-9.1

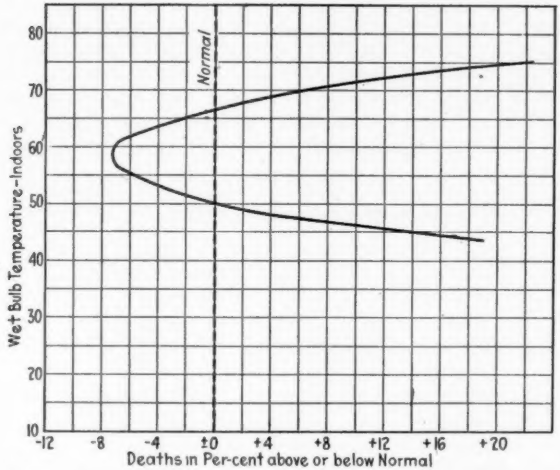

FIG. 4 MORTALITY CURVE BASED ON INDOOR WET BULB TEMPERATURE.

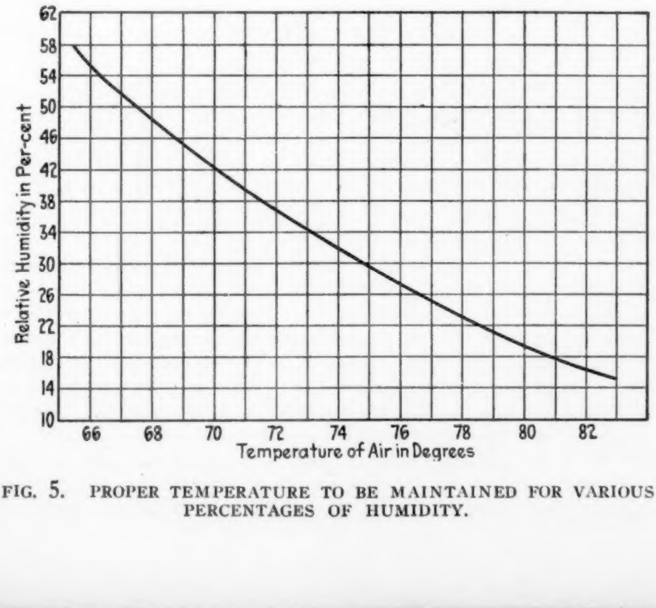

FIG. 5. PROPER TEMPERATURE TO BE MAINTAINED FOR VARIOUS PERCENTAGES OF HUMIDITY.

ANALYSIS OF RESULTS

Let us now analyze Fig. 2. Starting at the upper portion on the right, we find that when the temperature is 72 deg. the number of deaths is 11 per cent above normal. As the temperature drops the number of deaths decreases, and at 67 deg. the curve crosses the normal line. A further decrease will result in a departure below normal. This continues until 61 deg. is reached, when the curve

TABLE 2. AVERAGE PERCENTAGE MORTALITY FOR ALL MONTHS HAVING A MEAN WET BULB TEMPERATURE OF 24 DEG.

1. City	2. Percentage Mortality	3. Weight
Chicago	+27.28	87
Salt Lake City	+17.80	4
Portland, Me.	+24.35	2
St. Louis	+12.23	27
Spokane	–10.20	4
Louisville	+ 4.40	9
Denver	+16.32	8
New York	+18.90	187
Pittsburgh	+15.17	21
Buffalo	+10.36	17
Green Bay	+ 4.25	1
Cleveland	+15.10	22
Baltimore	+17.78	22
Boston	+ 9.60	27
Duluth	–12.70	3

Average 17.9 per cent above normal.

suddenly drops. From 61 deg. to 57 deg., other things being equal, the conditions of health are practically constant. This range marks the ideal condition, since any departure above or below these limits will result in a marked increase in deaths. As the temperature continues to fall the number of deaths increases at a rate of about 1½ per cent per degree until a wet bulb temperature of 45 deg. is reached. At this point an important consideration appears.

In so far as the curve has been analyzed, the conditions have been such that little, if any, heat in the building was required. Average temperature conditions indoors were practically the same as outdoors, but as the temperature falls to 45 deg. wet bulb, we approach the beginning of the heating season. This is indicated in the illustration by a horizontal dashed line. The portion above the line represents the non-heating season and that below the line the heating season. The upper portion of the curve shows that health varies with the wet bulb temperature and to continue the curve through the heating season, it is necessary to determine the wet bulb temperature that results indoors, as the air is artificially heated. It is

assumed that the average dry bulb temperature indoors for day and night is 65 deg. To determine the wet bulb temperature, it is necessary to know the grains of moisture present in the air. Since the amount of moisture depends only on the dew point temperature, the wet bulb temperature indoors may be closely approximated from the dew point outdoors.

TABLE 3. DEPARTURE OF DEATHS FROM NORMAL FOR VARIOUS WET BULB TEMPERATURES

Departure from Normal	Wet Bulb Temperatures
+ 6.23	72
+ 3.83	70
+ 4.74	68
+ 0.81	66
− 2.99	64
− 6.36	62
− 7.24	60
− 7.32	58
− 4.98	56
− 2.77	54
− 2.62	52
− 2.52	50
+ 0.53	48
+ 5.8	46
+ 6.44	44
+ 3.69	42
+ 3.34	40
− 0.39	38
+ 3.33	36
+ 4.03	34
+ 8.95	32
+ 8.58	30
+ 9.69	28
+13.00	26
+12.37	24

For example, when the dry bulb temperature outdoors is 47½ deg., the wet bulb temperature is 43½ deg., the dew point is 39 deg. The absolute humidity is 2.75 grains of moisture per cu. ft. As the air now enters the building by infiltration, it is heated to 65 deg. The absolute humidity is affected only by a change in the density of the air as its temperature is raised. Hence, a correction for the change in volume is necessary and the resulting absolute humidity indoors is 2.67 grains per cu. ft. and the dew point is 38 deg. With a dry bulb temperature of 65 deg. and a dew point of 38 deg., the wet bulb temperature indoors will be 51½ deg. In this manner it is possible to predict, in most cases within 1 or 2 deg., the indoor wet bulb temperatures in buildings where there is no artificial humidification and where the number of occupants is not large. It is evident that when our homes and offices are heated, health is influenced through the greater part of the day by conditions indoors. These conditions depend upon the dew point outdoors.

Again referring to Fig. 2 it will be seen that after a wet bulb temperature of 45 deg. is reached outdoors, departure of deaths is

influenced by some higher wet bulb, and the curve reverses. The curve continues in the reversed direction until a temperature of 38 deg. is reached. This point indicates the maximum benefit to be derived from the out-door dew point and usually occurs during November. After the point is reached, the dew point lowers and the wet bulb temperature indoors becomes less favorable. As the temperature continues to drop, the curve again reverses and runs nearly parallel to the corresponding portion of the non-heating season curve. To place the curve falling within the heating season on a basis of indoor conditions, the wet bulb temperature indoors was computed from points taken from the curve.

TABLE 4. INDOOR WET BULB TEMPERATURES CORRESPONDING TO OUTDOOR DEW POINT TEMPERATURES

Outdoor Wet Bulb Temperature	Departure of Deaths from Normal in percent	Approx. Outdoor Dew Point Temperature	Approx. Indoor Wet Bulb Temperature
43.5	+ 6.60	39.0	51.5
42.5	+ 5.00	38	51.2
41.5	+ 4.00	37	50.7
41.0	+ 3.00	36	50.5
40.0	+ 1.70	35	50.0
39.0	+ 0.40	34	49.8
38.0	− 0.50	33	49.5
36.0	+ 1.00	31	48.8
35.0	+ 2.00	30	48.5
33.0	+ 4.00	28	47.7
31.0	+ 6.00	26	47.0
29.0	+ 8.00	24	46.5
27.5	+10.00	22.5	46.2
26.0	+12.00	21.0	46.0

Table 4 illustrates how this change was made. Column 1 gives the wet bulb temperature outdoors. Column 2, the departure of deaths from normal, and Column 3, the approximate dew point outdoors. Column 4 gives the wet bulb temperature computed for indoor conditions. Column 2 and Column 4 were plotted in Fig. 3. The larger curve is for the non-heating season and the small curve for the remainder of the year. Both are on a basis of indoor conditions. A final curve which represents the true mortality based on indoor conditions for both the heating and non-heating season may now be drawn. This is shown in Fig. 4. The curve shows the relative importance of the wet bulb temperature and its relation to health. It definitely establishes the proper temperature limits.

The ideal temperature for physical health lies between 57 deg. and 61 deg. Any variation above or below this limit has a marked effect upon health, a variation of 2 deg. resulting in an increase in deaths of about 2 per cent. The significance of the wet bulb will be realized by assuming a condition that prevails in many of the homes in winter. Assume a dry bulb temperature of about 70 deg. and a relative humidity of 20 per cent. This results in a wet bulb

temperature of 50½ deg. and an increase in the number of deaths of about 6 per cent above what it would be if the wet bulb temperature were 57 deg. For New York City this would mean about 390 additional deaths every month.

Fig. 5 shows the proper temperatures to be maintained for various percentages of humidity based on the conclusions drawn from this study. It will be noted that the wet bulb temperature, ideal from the standpoint of health, very closely agrees with the temperature required for comfort. They can always be made to agree by maintaining the correct movement of air in the room. As the air motion is increased, the wet bulb temperature must be increased to maintain the proper conditions for comfort. With a wet bulb temperature of 57 deg., when at rest, we will require an air motion of 30 ft. per minute.

JOINT DISCUSSION OF PAPERS

on

THE RELATION OF THE DEATH RATE TO THE WET-BULB TEMPERATURE

By E. V. Hill and J. J. Aeberly, Chicago, Ill.

and

THE RELATION OF THE WET-BULB TEMPERATURE TO HEALTH

By O. W. Armspach, Pittsburgh, Pa.

The Author (O. W. Armspach): In preparing this paper, the general aim was practically the same as indicated in Dr. Hill's paper, to definitely and clearly establish the relation of the wet bulb temperature to health. The specific aim was to determine the proper temperature limits beyond which we should not go when artificially heating buildings. The conclusions have been reached by comparing the deaths with the temperature conditions in 27 cities selected throughout the United States and representing the various climates. The cities were selected so as to include all possible combinations of temperatures and humidities.

John Howatt: How does Mr. Armspach arrive at the normal death rate.

The Author: The dotted line in Fig. 1 on page 525 shows the actual number of deaths for each year. The full line shows the normal number of deaths.

The line shows the normal deaths or the deaths that would have occurred had there been no irregularities due to changes in sanitary conditions, population, and other minor effects. It is only an average curve in the sense that the points determining the normal are averages of the nine-year-periods. The average for each year will not fall on the normal line. The normal represents a progressive change from causes which act with regularity, and it eliminates all changes which act periodically.

John Howatt: In arriving at this normal death rate curve the conditions Mr. Armspach plotted in curves 2 and 3 are entirely

eliminated, the death rate varies with the wet bulb temperature, and in arriving at normal Mr. Armspach has paid no attention to the wet bulb temperature.

THE AUTHOR: The number of deaths is found that would occur in a particular city with the changes in population and sanitary conditions eliminated. Suppose during December, 1905, the normal number of deaths for the year in Chicago as taken from the curve were 36,600. This is divided by twelve to find the deaths for the month which is 3,057. Also suppose the actual number of deaths as taken from statistics were 3,436. The actual number of deaths, therefore would be 12.4 per cent above normal. In this manner, the variation of deaths above or below normal was found for each month and the city was compared only with itself. These figures were then compared with the weather reports of the corresponding months.

WM. J. MAUER: It is quite difficult to discuss this paper because of its entering two professional fields; but it appears to me that from a mathematical standpoint, the curve is not correct, as is set forth on page 524 where it says "The ideal wet bulb temperature to be maintained indoors lies between 57 and 61 deg. Dr. Hill's "comfort curve" shows 57 and 61 as variable, depending on the air motion and personal activity. It seems to me that it would be better if the authors would use the ideal wet bulb temperature to be maintained, the wet bulb curve as established by Dr. Hill, and any variations from it would then give the death rate in proportion to the distance from the curve. You will notice on page 518 Dr. Hill's curve.

There are two other points which occurred to me in reading this article; one is *death rate:* I wonder if in determining death rates, this point has ever been taken into account—the idea of giving consideration or value to the deaths occurring outside of the time of life when certain deaths are most apt to occur; for instance, diphtheria. It is hardly expected that a person at the age of 30 would have diphtheria, when usually only a child of 10 or 12 gets it. I think the diphtheria curve is already established and at what age the peak is arrived at. Therefore, if the peak for diphtheria is when a child is 10 years old, a person dying of diphtheria at about 20 years of age is out of the normal and the death rate should show a penalty for it equal to say 10 deaths of diphtheria, and so on.

The other point which occurs to me is in reference to the wet bulb and its variations as established by the curve. The curve shows what conditions are desirable for healthy persons; but it may be true that a sick person would require entirely different conditions. As for example, in tuberculosis, I believe the drier the air, the more readily will a cure be effected, and it seems to me for hospital work various degrees of wet bulb temperatures should be obtained and from these, it can be determined which particular wet bulb temperature is best for the particular disease.

A MEMBER: One paper describes the deaths in Italy and France, and the other discusses the deaths in the United States. We all

know the standards and conditions of life in France and Italy are different from those in this country. In some ways their standards are better, but in others, United States is far better off. Italy and France use different methods in heating. This would indicate that the wet bulb temperature would apply irrespective of the matter of disease or sanitary conditions in those homes. Yet those are entirely different countries with entirely different conditions.

E. S. HALLETT: In getting the data as to the deaths has the migratory feature been taken into consideration? For instance in Southern California, there is a large migration of diseased people and the death rate is very much larger than normal. In Florida, Colorado, Hot Springs, during the winter there is a great migration. Have these elements been considered?

E. V. HILL: I do not think that factor has any material influence. We have a record of non-resident deaths in Chicago, and the influence on the death rate from that record is so small, that it can almost be ignored. Mr. Hallett speaks of the migration to California; but think of the people that come into our large cities, for business and other reasons and die there. I think that one will about offset the other. I do not think it would have any appreciable effect.

J. R. ALLEN: The Bureau took up this question because it was one that is vitally interesting in determining the standard of ventilation. It was decided that it would not be important to take up the question of minor variations. To prepare a paper of this kind is more work than can be appreciated. It was necessary to approach the U. S. Government to get original statistics. Many of these statistics were made up in pen and ink, and the Government went to considerable expense to furnish us with those data. It took weeks of time with three people to compile these statistics, and if minor variations are taken into consideration impossible obstacles will be met. Besides it would take years to do the work. The value of a paper of this kind is largely in its general results. Of course the interesting fact is, that it coincides with Dr. Huntington's results, as shown by Dr. Hill, and also with Dr. Hill's chart.

JAMES A. DONNELLY: These ventilation schemes of ozone and humidity control look very attractive; but it seems to me that it is adding such a terrific amount of expense. I have seen more successes and failures in ventilation, I think, than in almost any other line. Years ago only wealthy residents received ventilation. I think ventilation is somewhat overdone, and if ozone and humidity control are added it will cost more than radium soon. Fresh air is really a luxury. In some cases, however, it is a necessity.

THE CHAIRMAN (J. R. MCCOLL): A few weeks ago I reviewed 32 schools in Detroit and figured the heat load separate from the ventilating load, and found that for every pound of coal used for heating there were 3 lb. used for ventilation. The 32 schools ranged in size from 16 to 32 rooms. I checked these figures with those of some other cities and found them very similar. The heat for ventilation

is approximately three times that necessary to take care of the building loss only.

E. S. HALLETT: We experienced that here in St. Louis and that is how I happened to break loose from the old pratice. In St. Louis also air was being wasted through the vent stacks, and it was necessary to find some way of correcting it. We didn't want to reduce the ventilation, and we saw the cost was coming high. Thus the ozone was the solution of it; we could re-circulate the air and have no loss of heat, and we found that in this way we had greater satisfaction than before when we wasted the air.

H. M. HART: I am glad this point has been brought out. Taking Mr. Donnelly's viewpoint, are we going to sacrifice the health of the public for the sake of saving dollars; I don't think the dollars are going to do the public any good if the public has to sacrifice its health to them. If we had a sack of dollars in one hand and good health in the other, and offered it to the public, I don't think there would be much question, but what they would choose good health every time. Therefore, I think the expense is of secondary consideration and good conditions of sanitation and living are the first.

E. V. HILL: If I understand Mr. Donnelly's remarks, he means that clean air, properly tempered and so on, is not free as it is used today. It is expensive and, if I read between the lines of what he says, there is considerable objection on the part of a good many people, school boards, and people who are building, to spending the money necessary to get this result; so he would adopt a new policy of only supplying clean air in abundant quantities to the people that can afford to pay for it, for instance, put it in our better class schools, and let the others do without it—they do without lots of things, why not without this. It is the same in our theatres; where the Grand Opera is visited by the well-to-do, they can afford to have ventilation, and in the nickelodeons they can do without. I think there is food for thought in Mr. Donnelley's suggestion.

I want to ask Mr. Armspach in reference to his second conclusion: "During the heating season physical health depends upon the dew-point temperature outdoors, the most favorable dew point being the one that will result in the highest wet-bulb temperature indoors." I think that should be qualified. During the heating season, physical health depends upon the dew-point temperature outdoors, assuming the air is not humidified or otherwise altered. Simply by warming the air we get maximum results under heating conditions, but that does not mean that we could not humidify the air indoors and get ideal conditions at any time.

HENRY BAETZ[1]: In connection with the subject of ozone and humidity, is it assumed that the problem of ventilation and the bringing of fresh, natural air into the room, has thereby been solved? To my mind there is something yet to be done in that direction, which

[1] Skinner Bros. Mfg. Co., St. Louis, Mo.

is really more attractive to this Society because the solution of that problem would not bring us into the medical field, as would the question of ozone and its effect on the health. The first object of the ventilating engineers should be to bring the pure air of nature into the room so that the occupant can breathe it and be surrounded by it. With practically all ventilating systems now in use, the air which the occupant breathes and is surrounded by, has first been used to carry the heat units that warm the room, and only after that it comes to the person for inhaling. As a result I believe the air is injured as far as human requirements of breathing are concerned. I might illustrate it in this way: If a floor is mopped, the mop wrung out, and further mopping is done, after which the water is left to settle and then is served for drinking purposes, of course, everyone would revolt; but nearly the same thing happens to the air that is breathed to-day in a heated room. Air leaves the radiator in excess of 100 deg. temperature and enters the room above that. The only way its temperature can be lowered so that the particular air will come to the breathing level in the room, is that it must strike against the cold walls. In that proceeding the air fares similarly to the water used for mopping floors and becomes impure from having sought out every nook and corner where impurities lodge. The air ought to be introduced into the room at such a degree that it will naturally take its position at the breathing level, which means that the air that is to be inhaled will not be used to do the heating first.

P. NICHOLLS: I can see that it is rather dangerous and difficult to draw definite conclusions from a mass of data like that submitted, and that it is safer to trust to the general deduction than to attempt to fix the actual events that have happened. The question that occurs to me is this: What effects have the different wet bulb temperatures on the actual health? Is it that it makes sick people die sooner, or, do they live a few weeks longer with a favorable wet-bulb, or is it that it makes well people sick, so that they die? Then again, it does not follow but the same number of people might not have died in the year. Some might have died sooner, and some later, but the actual number might be the same.

However, first of all we are interested here in what difference would an improvement in the heating and ventilating of a house have. That brings up the question as to what percentage of the trouble causing death or illness is due to the house and what percentage of trouble is due to outside conditions of which the house and living conditions indoors have nothing whatever to do. According to my mind the data would bear a further analysis, and the application of the method to a confined area to show the relationship of a part to the whole. The return from the money invested in proper heating and ventilation is measured by the increased comfort and efficiency that results, and the decrease in death rate would have comparatively small weight.

No. 577

DISCUSSION OF PROPOSED STANDARD FOR VENTILATION

The Chairman (J. R. McColl): It is the consensus of opinion of the officers of the Society that we should now establish a standard of ventilation. The matter was brought up and discussed at the last Annual Meeting and deferred for further consideration until this Meeting. We will now call upon Director Allen to discuss the desirability of some move, to state why it is desirable, and outline what in his judgment we should do at this meeting.

J. R. Allen: There is a great demand made upon the Society for an exact definition of ventilation. In fact, one of the objects of establishing the Research Bureau, was to establish a standard for ventilation and methods for determining that standard. The more the Research Bureau goes into the investigation of ventilation, the more we feel that the points brought out by Dr. Hill's charts are the essential points to be covered. This chart has made a very excellent start towards a standard of ventilation. Any standard which may be set up for ventilation, no matter what it is, will be found more or less imperfect, and eventually will have to be modified and changed to suit conditions. That has been the history of every standard. We have been through that particularly in the Boiler Code Committee of *The American Society of Mechanical Engineers* and others. Now, I think it would be wise at this time to adopt this Synthetic Air Chart for the standard of this Society and then correct or modify it as its use would suggest; and with this in mind I would like to offer the following resolution:

First—RESOLVED: that the Synthetic Air Chart be adopted as the standard of the Society for measurement of ventilation;

Second—RESOLVED: that a committee of five be appointed by the President to study the Synthetic Air Chart and amend or revise it if this appears desirable, the committee to report at the Annual Meeting in January.

The motion was seconded.

A Member: I would offer as an amendment to this resolution that instead of a standard of ventilation we say a standard of measurement of ventilation.

J. R. Allen: I accept the amendment.

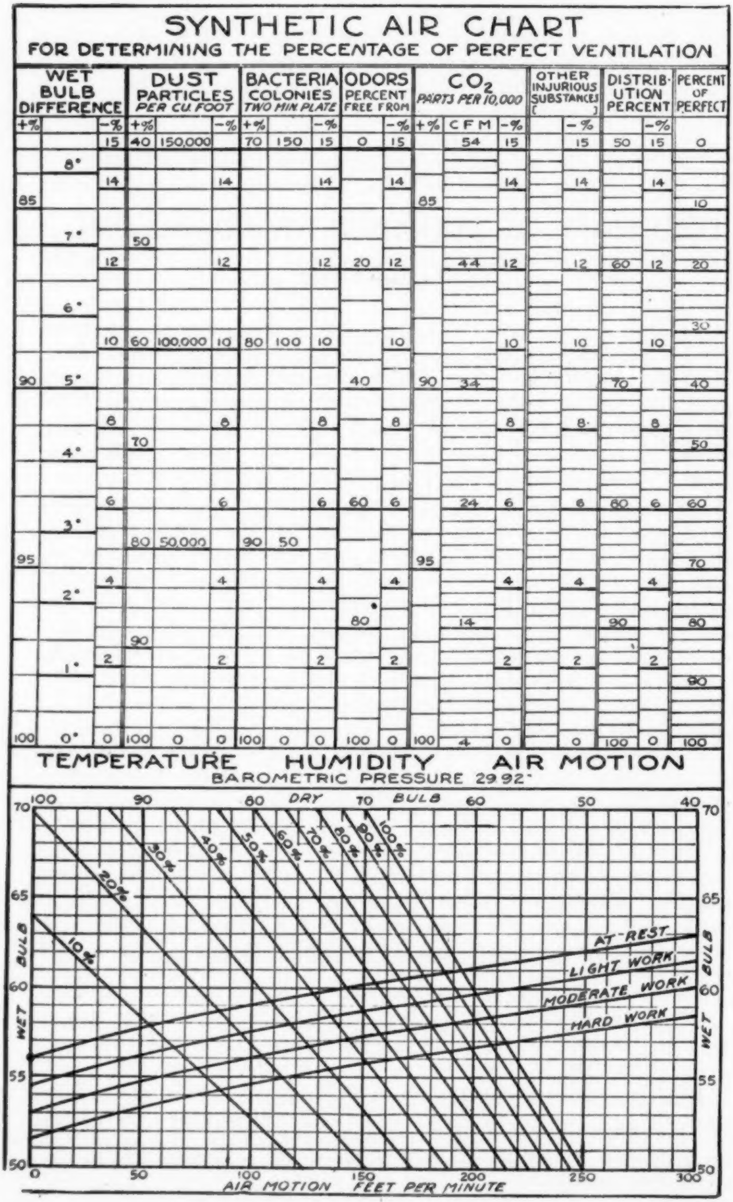

FIG. 1. THE SYNTHETIC AIR CHART.

W. J. Mauer: I wonder if it was due to diffidence on Dr. Hill's part that his name is omitted on the chart. I think it first came out as Hill's chart. He has worked on it for over five years. If the chart should ever be changed, it would be referred to in the future as Hill's chart, and I would like to make an amendment, to the effect that the word "Hill's" be added to it.

E. V. Hill: That name was never on the chart and never will be. I wish to ask Prof. Allen to amend his motion about appointing a committee. Prof. Allen is Director of the Bureau of Research, and he made a suggestion the other day that someone who is unfavorable towards the chart should be on this Committee, and it is perfectly natural, as it is my creation, that I should be inclined to appoint members who are favorable. I will, therefore, ask Prof. Allen to appoint the Committee instead of myself. In 1912, which was the first Annual Meeting in New York that I attended of this Society, I argued for the adoption of a standard method, and we have been continually striving towards that end up to the present time. This is the eighth chart form we have devised and experimented with, and it is the only one we have not been compelled to discard. We can talk about so many cubic feet of air, but that is not what we are after. There are many factors to be considered, if a proper understanding is arrived at. These factors are shown at the top of the chart, the first one is the wet bulb, and I am, of course, very much pleased that our Research Bureau has arrived at practically the same standard as shown in this chart. Now, the theory of the chart is as follows: we establish as a base line the ideal condition, which is 56 deg. wet bulb temperature in still air. The other extreme of wet bulb temperature is that under which life ceases to exist; the wet bulb temperature is so high that a person would succumb in a short period. This would be at the top of the chart, at 102 deg.; that is not absolutely accurate, but sufficiently close. It means that if a person is subjected to 102 deg. wet bulb temperature or supposing the temperature is 102 deg. and the humidity 100 per cent, then the wet and dry bulb temperatures would be the same, so that no heat would be given off by the human body, for the temperature of a human body is about 96 deg. and that would cause death. The ideal condition is clean air and the other extreme is a measure of air so small that life would cease to exist. We have taken these various factors and weighted them in that way. Each one is separate and complete in itself, and if the wet bulb temperature is 102 deg., no matter if all the rest of the conditions of the chart are perfect, the final percentage would be zero. Or if perfection in temperature and bacteria could be attained and there were less than 3 cu. ft. of air, that would be zero on the chart, and zero would be the total. So, as far as those factors are concerned, it is a mathematical proposition that cannot be questioned. The only trouble is with regard to dust, bacteria, and odors. No one can say how much dust, bacteria, and odors will cause death. It may be said that if the air is perfectly clean with respect to dust and bacteria, and absolutely free from objectionable odors, the percentage will be 100. So to

arrive at this combination of factors some tests were made in a rag-picking shop in Chicago, the worst I have ever seen with regard to dust, bacteria, and odors. It is printed in the report. There were 26 employees, and I believe 9 or 10 of them were found to have tuberculosis at the said time. It was a condition where life would cease to a large number of the employees in a short time. Now, methods of testing and determining all of these various factors have been worked out and the figures at the right of each column of the chart are deducted from the value determined in arriving at the final percentage. For instance in the first column, if the tests show 2 deg. of wet bulb temperature that means the wet bulb temperature is 2 deg. away from perfection, and it is the same procedure in every column, so all that is necessary is to make the test, add up the percentages, subtract them from 100 and there are the results, making a percentage of 85 per cent, or whatever it might be. Now, in conducting a test in first-class mechanically-ventilated class rooms, it was found that the percentage was 92, 92½ and sometimes as high as 94 per cent. That is, it reached 94 per cent of perfection. On a June day this same test was made and 99 per cent was obtained. In factory buildings where it is crowded and ventilation is inadequate, the percentage was about 75. This offers a method of recording all the factors that influence conditions. As Prof. Allen says, it is subject to correction as more data are obtained. I am strongly in favor of having the Society adopt some such method that will serve as a convenient method of determining what tests of ventilation signify.

A MEMBER: I would like to ask Dr. Hill just how he arrives at the values to give the different factors? That is, each one of those different factors have a weight, and the wet bulb difference of temperature has probably a different weight as to value in its effect on ventilation than the odor.

E. V. HILL: For instance, take the wet bulb temperature; the chart runs from zero to 100 per cent; zero is where life ceases to exist and 100 per cent is perfection. Now, if we have a wet bulb temperature of 6 deg. away from ideal, that would be a minus percentage of that much.

A MEMBER: In arriving at that per cent of perfection, please explain what weight you give each of those factors.

E. V. HILL: In arriving at our final percentage, let's assume that our test shows 25 per cent of wet bulb difference, that is, that our test on the wet bulb was 75 per cent of perfection. Supposing these other columns were ideal, we will then subtract 25 from 100 and that gives our final percentage as 75. Now, supposing that the wet bulb was 75 per cent of perfection, the dust was 75 per cent of perfection and the bacteria were 75 per cent of perfection, we would add up the minus factors which would be 25 in each case, or a total of 75, and substract that from 100, and our total percentage would be 25. It does not make any difference whether it is perfect or zero; this is always subtracted from 100 and each one of these values is a distinct entity in itself.

A MEMBER: Does that give each factor the same weight as any other?

E. V. HILL: It must have the same weight, because the range of this is from perfection to where life would cease to exist at zero. It doesn't make any difference whether one dies from lack of air or from a high bulb temperature; the result is the same.

A MEMBER: In this chart there are a good many factors that would not result in death.

E. V. HILL: The central columns are divided into three; dust, bacteria, and odors. It is impossible to say exactly where that would result in death, and so we took the condition in the rag shop and combined all of those as one factor.

A MEMBER: Do you take the sum of those three and divide it in order to arrive at your per cent?

E. V. HILL: Yes, but we do not need to do that. In fact, it has been worked out on the chart.

THE CHAIRMAN: I understand this resolution that is before the Society enables the Committee to make some readjustments of values? All in favor of the motion, vote in the usual manner; contrary, likewise.

The motion was carried.

JAMES A. DONNELLY: There has arisen a significant question as to the definition of a "standard," and I have something very short that I would like to offer. It might properly be referred to the Research Bureau, and perhaps be passed over to the Annual Meeting where we could discuss it at greater length: "Resolved, that the standards accepted by this Society shall represent a fair average of the best of present practice."

In looking through the dictionaries and encylopedias I haven't been able to get a standard from our point of view, and if we were now to define a "standard" it might be helpful.

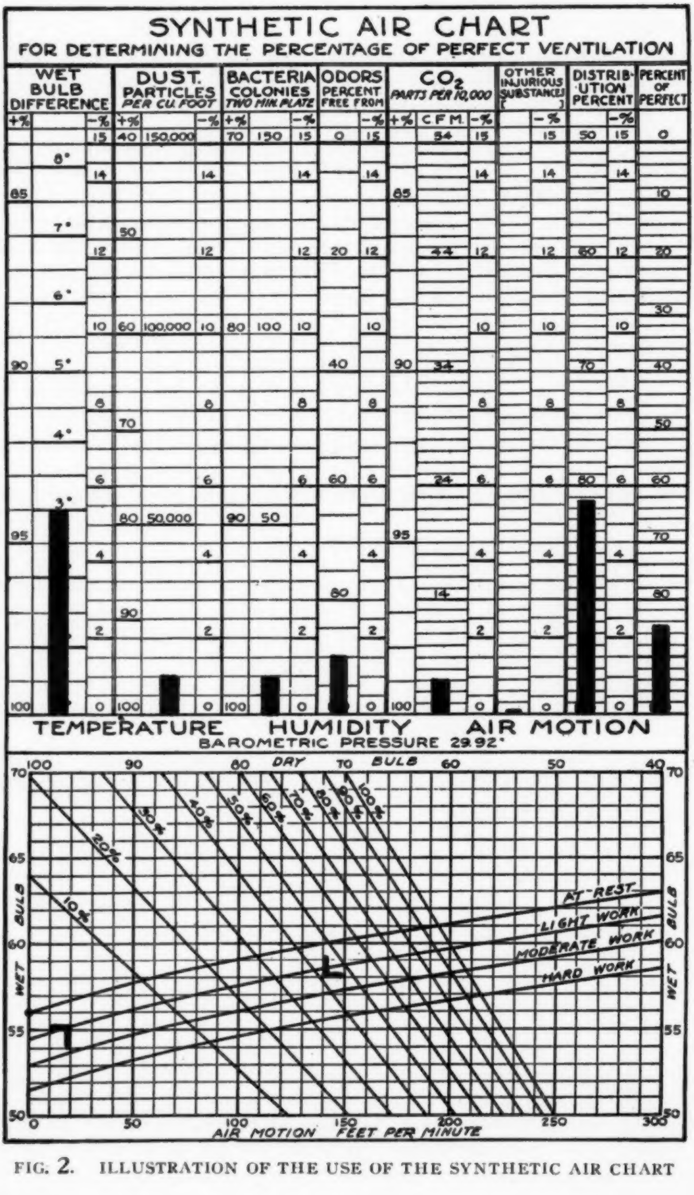

FIG. 2. ILLUSTRATION OF THE USE OF THE SYNTHETIC AIR CHART

MODUS OPERANDI OF THE SYNTHETIC AIR CHART

In view of the announcement that after three years of investigation of the question of a standard for measurement of ventilation, the Society had adopted the Synthetic Air Chart for the purpose of comparing the air conditions in any room with the ideal or standard conditions, the Research Bureau worked out the following description of its method of application. It was thought that the operation of the Synthetic Air Chart might not be found entirely clear without some explanation and the Research Bureau submitted the following brief statement for the benefit of those interested, together with illustrations of the apparatus necessary to make the measurements involved.

THE Synthetic Air Chart offers a means of determining the percentage of perfect ventilation by considering all the known factors that make up the air conditions in a room. These factors with their proper weights, experimentally determined, are represented by columns arranged vertically across the chart. The base of each column represents the ideal condition, or 100 per cent perfect. Bordering on either side of the main column are two narrow columns marked "—%" and "+%." The former denotes the penalization to be subtracted from the Percent of Perfect column, and the "+%" denotes the condition considering only the one particular factor.

The various factors are divided into three groups which are separated by the double lines. *First,* Wet Bulb Difference which includes Temperature, Humidity, and Air Motion; *second,* Dust, Bacteria, and Odors; *third,* Carbon Dioxide. The latter, although not really a factor, since it is not considered injurious, serves as an index of the amount of air supplied and of the distribution in the room. In addition, columns providing for Other Injurious Substances and for Distribution are given. The upper limit of any of these groups represents the condition where life would cease to exist. Hence at this point the "—%" column would indicate 100 per cent penalization. (Since the upper ends of the columns represent conditions not obtained in practice they are not included on the chart.)

To illustrate the method of graduating the columns, consider the first which is headed Wet Bulb Difference. When at rest with no air motion, the ideal wet bulb temperature is 56 deg. The upper portion of the column represents the unlivable condition which is approximately 106 deg. with 100 per cent humidity or a wet bulb difference of 50 deg. from the ideal. Any variation from 56 deg. would therefore represent a definite percentage of variation from the ideal. The graduations in the other columns were constructed in like manner.

After the values of all the factors have been determined by test, the results are shown on the chart by a heavy vertical line (1/8 in. wide) and the height of the line will indicate the results obtained in the test. Penalizations for all the factors may then be read directly opposite the top of each line. All the "—%'s" are then totaled and the sum subtracted from 100 per cent to determine the Percent of Perfect ventilation for the room as a whole. This result is plotted in the last column headed Percent of Perfect. For example, if the sum of all "—%'s" found in the different columns is 15 3/8, per cent, then the difference between 100 and 15 3/8, or 84 5/8 per cent, is plotted in the last column as the final Percent of Perfect.

TO MAKE THE TEST

Temperature, Humidity, and Air Motion.—Temperatures and humidities shall be determined with a sling psychrometer. The

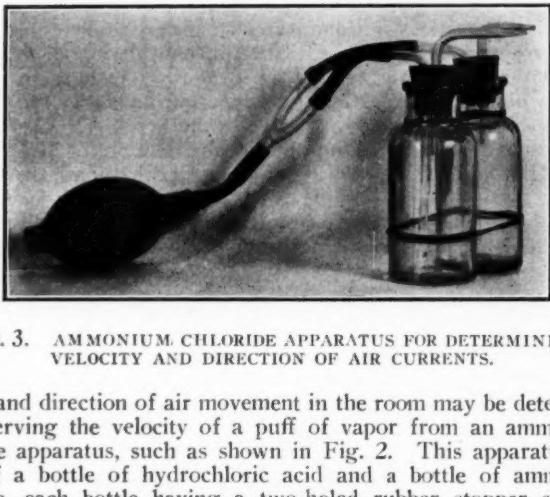

FIG. 3. AMMONIUM CHLORIDE APPARATUS FOR DETERMINING VELOCITY AND DIRECTION OF AIR CURRENTS.

extent and direction of air movement in the room may be determined by observing the velocity of a puff of vapor from an ammonium-chloride apparatus, such as shown in Fig. 2. This apparatus consists of a bottle of hydrochloric acid and a bottle of ammonium chloride, each bottle having a two-holed rubber stopper supplied with bent glass tubing similar to a wash bottle. A small pressure bulb forces the air through the two bottles simultaneously, and when the acid vapors and the ammonium vapors unite, a cloud of ammonium-chloride vapor is formed. This cloud is readily visible and the velocity and direction of the air currents may be studied from it.

Dust. Dust determinations are made by the use of a direct-counting instrument in which the air is caused to impinge against a cover slip coated with adhesive material. The particles are counted under the microscope and the result placed upon a cubic foot basis. By direct counting is meant a method where the dust particles are studied and counted as they originally existed in the air, and the particles are not broken up or altered in shape, size, or nature by processes of sampling or counting.

Bacteria. Bacterial determinations shall be made in accordance with the standard adopted by the American Public Health Association. Petrii dishes 4 in. in diameter (see Fig. 3) containing standard agar, are exposed in the room for two minutes. They are then carefully covered and incubated for 48 hours at 22 deg. cent. The colonies on the plate are then counted.

Odors. Odors shall be determined in accordance with the following rating:

100 per cent freedom from odors.............	Perfect
95 per cent freedom from odors.............	Very faint
90 per cent freedom from odors.............	Faint
85 per cent freedom from odors.............	Noticeable
80 per cent freedom from odors.............	Distinct
75 per cent freedom from odors.............	Decided
70 per cent freedom from odors.............	Strong

FIG. 4. CULTURE PLATES FOR DETERMINING THE BACTERIA IN AIR

The determination shall be made immediately upon going into the room from the outer air.

Carbon Dioxide. The apparatus necessary to take samples of air for CO_2 determinations consists of a 120 cu. cm. rubber-stoppered bottle and a constant-pressure rubber bulb, as shown in Fig. 4. To take a sample, the rubber tube attached to the bulb is inserted to the bottom of the bottle and held at arm's length so that the sample will not become contaminated by expired air. The tube is closed by compressing it between the thumb and neck of the bottle and the net-covered bulb is filled with air by pressing the uncovered bulb with the hand; the thumb is then released and the inrushing air replaces the air originally in the bottle. This operation is repeated three times, after which the tube is removed and the bottle is tightly sealed with a rubber stopper. An analysis of the sample is then made with a Peterson-Palmquist air-analysis instrument, the result being given in parts of CO_2 per 10,000 parts of air.

In the chart in Fig. 5 is shown how the air supply may be determined from the CO_2 readings. Suppose an analysis of the air sample taken in the room shows that the average CO_2 content is 7 parts per 10,000. Then if the outdoor air contains 4 parts per 10,000, the difference is 3 parts. Locate the 3 on the horizontal scale of the chart, and pass vertically up to the curve; from the point of inter-

section with the curve tranverse to the vertical scale which will show that 2000 cu. ft. of air per hour per person are being supplied to the room.

Distribution. The distribution of the air in a room shall be determined from the CO_2 readings taken in the various parts of the room. The following example illustrates the method of calculating the result. Assume four samples taken resulting in the following analysis:

Station	*Parts of CO_2 per 10,000*
1	6.4
2	7.4
3	9.2
4	5.0
	Average 7.0

FIG. 5. TAKING AN AIR SAMPLE.

The variation at the various stations above or below the average is as follows:

Station	
1	$7.0 - 6.4 = 0.6$
2	$7.4 - 7.0 = 0.4$
3	$9.2 - 7.0 = 2.2$
4	$7.0 - 5.0 = 2.0$

Then the average variation from the average CO_2 is determined as follows:

$$\frac{0.6 + 0.4 + 2.2 + 2.0}{4} = 1.3$$

The percentage of variation is therefore equal to 1.3 ÷ 7.0 = 18.6 per cent. Therefore the percentage distribution = 100 — 18.6 = 81.4 per cent.

Other Injurious Substances. This column is used only in special cases where, owing to the nature of the processes carried on, some particularly injurious substance is being given off to the air. The column is then graduated, consistent with the nature of the substance.

For example, suppose that the contaminating substance is carbon monoxide. Grubner states that symptoms of poisoning are distinct when the air contains 0.02 of one per cent of this gas, and that death ensues in a short time when the air contains 0.05 of one per cent.

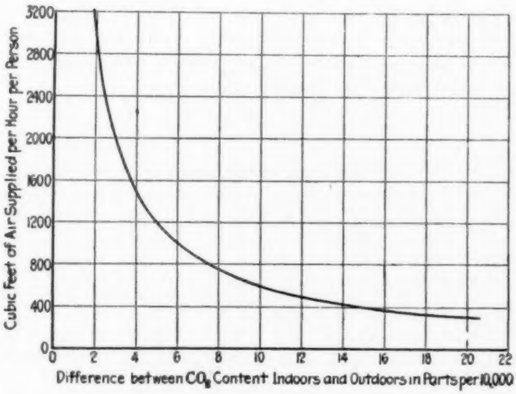

FIG. 6. CURVE TO DETERMINE AIR SUPPLY FROM CO_2 READINGS

Whitthaus states that when air containing carbon monoxide is breathed, the body retains about one-half of the gas inhaled. The poison therefore accumulates in the blood, and small amounts in the air may produce death if inhaled over a sufficient period of time. It is apparent therefore for our purpose that the lethal dose of 0.05 of one per cent is too high, and that 0.02 of one per cent, considering the time factor, would be nearer the truth. In arranging our scale in the column headed Other Injurious Substances, we would therefore consider air free from CO as 100 per cent and air containing two parts in 10,000 as 0 per cent, or air containing one part of CO would be 50 per cent, ½ parts, 25 per cent, etc.

For example, if a test is made of the air in a garage or other place where CO is found, and the result shows two parts of CO in 100,000 parts of air, the penalization factor would be 10 per cent, and this amount would be added to the other minus percentages or penalization factors, and the total subtracted from 100 to obtain the final Percentage of Perfect.

The Comfort Chart. The inter-relation of temperature, humidity, and air motion is shown in the lower portion of the chart. The intersection of the Air Motion line and the Physical State line determines the proper wet bulb temperature. This point should be indicated on the chart by a small angle (thus ┐) the apex of the angle coinciding with the point of intersection of the lines. The observed dry bulb and wet bulb is also indicated by an angle (thus └). The difference between the *desirable* wet bulb and the *observed* wet bulb is plotted in the first column of the air chart marked Wet Bulb Difference.

Number and Location of Stations. The number of stations where samples are to be taken shall be determined from the floor area in the room. One station should be allowed for each 200 sq. ft. of floor space. In no case shall less than four samples be taken. The room should be divided equally into imaginary areas and a station located in the center of each area. All samples are to be taken in the breathing zone which is from 2 to 6 ft. from the floor.

RECORDING THE RESULTS

To illustrate the method of determining the Percentage of Perfect ventilation, consider the results of a test as given below. The average results in a room are found as follows:

Dry Bulb temperature	72°
Wet Bulb temperature	58°
Air Motion	20 ft. per min.
Physical State	Light work
Dust	10,000 particles per cu. ft.
Bacteria	10 colonies on a 2-minute plate
Odors	90% free from
CO_2	7 parts per 10,000
Other injurious substances	None
Distribution	81.4

These values are now represented on the chart by a $\frac{1}{8}$ in. vertical line drawn in the center of each of the respective columns. The proper wet-bulb temperature is determined by noting the point of intersection of the *light work line* and the 20 ft. *air motion line;* this is 55 deg. wet bulb. Since the actual wet-bulb temperature as determined by the test is 58 deg. then the wet bulb difference is 3 deg. This value is plotted in the first column and the penalization as read in the "—%" portion is —$5\frac{3}{8}$ per cent. For the 10,000 particles of Dust, the penalization is a —1 per cent; for the Bacteria, —1 per cent; for the Odors —$1\frac{1}{2}$ per cent; for the CO_2, —$\frac{7}{8}$ per cent; for Other Injurious Substances, —0 per cent, and for Distribution —$5\frac{5}{8}$ per cent. The sum of all these penalizations is —$15\frac{3}{8}$ per cent. Therefore the Percent of Perfect ventilation in the room is $100 - 15\frac{3}{8} = 84\frac{5}{8}$ per cent. This value is then plotted in the last column marked Percent of Perfect.

JOHN R. ALLEN,

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No. 578

COMMERCIAL DEHYDRATION

By Jonas E. Whitley[1], B. S., New York, N. Y.

Non-Member

Under the pressing demands for vast quantities of foodstuffs to be shipped to the armies in foreign countries, dehydration has become of great importance on account of the tremendous economy in handling certain materials in dried form. The Society, during the period of the war, devoted its patriotic efforts toward cooperating with the Department of Agriculture in furthering the technique of this industry as is evidenced by the numerous technical papers presented on all phases of the subject. In these papers, the practicability of dehydration has been clearly established, but the scope of the field has not been carefully analyzed. In the following paper, the author undertook to show some of the commercial possibilities and he established in an unquestionable manner some of the economic advantages of dehydration which have an important bearing upon the high cost of living.

THE Civil War gave us the canned vegetable. The war just closing has given us a substitute in the shape of the dehydrated food product. This latter overcomes all the disadvantages of the canned output—and they were many— and gives us in addition to all its benefits many of much greater weight. An army in the field must have a steady food supply or it soon ceases to be an effective force. Our boys in blue found this supply in the millions of cans which were sent to the front in 1861 and with the coming of the present great world war, with its problems far more difficult of solution, a demand arose for something better. This was met, in part at least, by refrigeration and dehydration and out of the effort dehydration emerges as the coming food preserver, not only as a war demand, but for meeting from now on, the greater requirements of peace-day industry.

It can do this and do it well, and without any of the draw backs which go with the refrigerating and canning processes. There is no

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loss in nutrition by the more modern process of drying, while the savings in manipulation and in cash outlay are so large that plain business figures sound almost like efforts at romantic exaggeration.

One new thing which came from under the stress of war conditions has put the whole dehydrating process on a new and absolutely scientific basis. This new departure is the vacuum drying method and the story of its coming is most interesting. Even before this country had entered the struggle, insistent demands were made upon us for war rations by those who were later our Allies. Shipping room was scarce and uncertain and this at once put a ban on the clumsy canned product and the expensive and uncertain frozen supply. There were soldiers at the front in the parched plains of the near East and others in the frozen region within the Arctic Circle. Everywhere there were the stomachs of fighters to be filled with an abundance of the best.

The problem was put up to the experts at the Harriman research laboratory in New York and they in turn enlisted the personnel and facilities of Columbia University. These experts had been long familiar with the ordinary drying processes applied to food. Some of these processes preceded even the coming of the white man to America and were employed when the plains of the great West were given over to the red man and the buffalo; the savage had already discovered that the flesh of the huge bison when hung in shredded festoons from the tepee roof was a very satisfactory addition to his limited larder. The white pioneers, too, found this "jerked beef" very edible. The investigating scientists, under the demand for meat and yet more meat, concentrated their efforts on a more modern meat drying process.

Now every laboratory has a vacuum drying chamber, used daily in the ordinary processes of quickly removing moisture at the lowest possible temperature. These were exactly the conditions necessary to work out this problem under which they were to provide raw meat with its moisture content removed. A few tests solved the whole question. This highly nitrogenized material was deprived of weight and water at the one operation, and was then ready to stand the vicissitudes of war transportation and to reach the mess table in perfect condition, with such slight culinary manipulation necessary that even the most careless cook could not go awry. The tons and tons of water which were removed in America were replaced at the fighting front and the difficulty was bridged. It was tried out at once to the extent of thousands of pounds. The dehydrated meat was sent to camps, to hospitals, and to starving civilian populations and from all came the one chorus of commendation.

This then, was the one novelty which was given to mankind as an indirect outcome of war necessity, and it is this which makes it possible now to readjust our whole study of the dehydration.

The ordinary drying processes, exposure to drafts of warm air forced over the material under treatment, and the sun bath method,

both fall into the discard when tested beside the exact vacuum treatment. The finished product tells the story at a glance. Instead of the discolored oxygenized product which comes from the blowing of hot air through the drying mass, the vacuum chambers' intake and output show absolutely no change save the water loss. Flavors are preserved to the most minute degree. Onions and garlic do not lose their characteristic pungency. Those mysterious yet tremendously important vitamines are still ready to do their work in the wonderful stomach laboratory. Neither the eye, nor the palate nor the digestive demands are offended in the slightest degree. Fish and

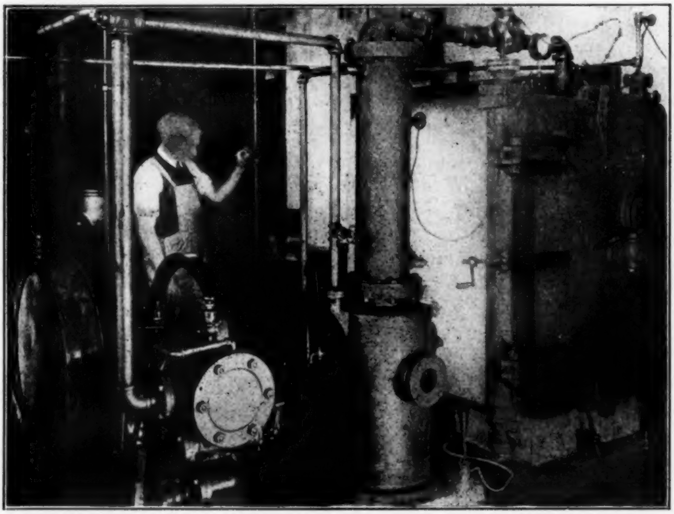


FIG. 1. COMPLETE WORKING UNIT, SHOWING VACUUM CHAMBER, CONDENSING CHAMBER FOR EXHAUST VAPOR AND THE VACUUM PUMP.

meat, which were out of place in the air and sun processes, are one with vegetables in the vacuum chamber. Salmon steak retains its characteristic color and the common cod comes to the fish cake in perfection. Clams, too, are ready for chowder uses months after they were taken from their shells, and even the oyster once out of his shell, although he becomes a dry chip for a while, readily *waters up* and makes a delicious fried oyster at short notice and without any possible chances of danger from ptomaine or other infection.

Now the question goes to the great army of food purveyors, from the farmer source through the channel of engineering skill and so on through the wholesale and retail grocers, and under the impetus of skillful publicity agents to the mouths of hungry millions, and

this with such a saving in expense that our present bugbear— the high cost of living—will be given the fatal knock-out blow.

That is the general proposition and, carried down to the minutest details, the wonder only grows, that the great saving has not been made immediately effectual and that the old style extravagant wasteful methods have been permitted to continue their organized system of robbery of the people at large.

The data on this vast subject are piling up at a rapid rate. In Washington, the National Department of Agriculture has kept abreast of every advance that has been made and is in position to advise the farmers individually or through the great grange organization, on the outlook from any point of view, while for the capitalist who may be attracted by the investment openings, there is a vast array of figures from which he may work out great cash dividends.

There are no more uncertain experiments to be tried. The process has been practically standardized. The plant calls for the ordinary vacuum chamber, such as a dozen foundries can supply, for any food output, vegetable or animal. It calls on the expense side for coal to supply warmth to the steam coils which underlie the food trays and for power sufficient to work the vacuum pumps. That is all. The cost of this machinery will vary with the size of the unit used and this in turn will be fixed by the factory door supply of raw material. As a general figure, $2 per lb. per day of wet material is a liberal estimate for the plant proper. This would make for a 24 hour run on a 3 ton wet intake a cost of $12,000 for machinery. The output weight would vary from 10 per cent in the case of some vegetables, to 33 per cent in the case of meat or other flesh products. The preparation of the material before treatment is the same as with the present drying plants and the packing and storage likewise are quite similar.

The great savings are in the other necessary demands of the icing and canning methods now employed. An example will bring this out in sharp relief. Take a case of canned tomatoes, costing say $4. There are two dozen tins making a gross package weight, mostly water, wood and tin, of 60 lb. The original cost at the farm gate for the raw material is 15 ct. and when desiccated in the vacuum chamber returns 2¼ lb. of dried tomato and this is all the weight to be shipped to the ultimate consumer. This means, in plain words, that by the canning method, it has cost $3.85 to preserve 15 ct. worth of the edible. When this exhibit is expanded to the millionth power it shows more and more the utter unbusinesslike methods of the whole present industry. Where one carload direct starts from the farm to the consumer, that same amount would fill 30 cars full of tin cans and packing; but that is not all. A few paper cartons suffice for the dry product, whereas in a *canned* carload, there are 10,000 lb. of tin and about 14,000 lb. of lumber and all this material calls for an army of skilled mechanics and a vast amount of hauling to

get it to the food factory sites. All this double handling of material, which is now tossed aside, pushes up the transport problem until on final analysis the haulage total means 105 carloads for the canned output against the one carload of the superior and in every way more desirable dehydrated product.

So much for the canning process. With refrigeration the figures are equally variant. Sprouts when green call for ice to check wiltage and a shipment of 50 lb. for a distance calling for a 12 ct. expressage rate, requires at least 100 lb. of ice on which expressage and labor is paid until the total transportation cost runs up to $18 and every grain of the food value would be in a dehydrated parcels post package, sent any distance in the United States for 30 ct.

There are many side lights on these questions. Take vegetables for instance that are charged with various mineral salts needful for the human system. The water in the can leaches out a large share, and the housewife seeking only the solid content throws away the very life of the peas, or corn, or tomato while dehydration always fixes it for permanent use. Again, catering to the eye calls for a rough and ready bleaching operation and the food profiteer, when air and sun are depended upon, resorts to sulphuring to get a showy output. Apples when dried other than by the vacuum process are given this treatment. The sulphur is burned under the trays of moist fruit and it is the sulphurous acid vapor generated which brings about the chemical reaction; in mines sulphur is often found associated with the equally volatile arsenic and the arsenious acid let loose tends to remain on the apple and may readily become a definite menace as a poison.

In the United States, the whole subject of dehydration has been left to the general government to consider. Although every state in the union has a commissioner of agriculture looking after the plant welfare of the state, it often seems to be a department in name only. A circular letter of inquiry was sent out asking these several commissioners about the drying industry in their states. In fully 75 per cent of the states the answer said nothing was known of it, and yet they were situated in the leading agricultural regions. There were marked exceptions. In some cases where large cities were convenient, the growers found a ready market for their fresh output. Oregon sent no reply; yet it has some very progressive workers in this line, and the neighboring state of California, the banner state today on this line of effort, gave some figures for 1918 that are well worth quoting. It reported a production of dried fruits or vegetables as follows: potatoes, 2,250 tons; onions, 175 tons; carrots, 100 tons; turnips, 40 tons; spinach, 40 tons; cabbage, 12½ tons; sweet potatoes, 2½ tons; rhubard, 5 tons; prunes, 45,000 tons; raisins, 167,000 tons; peaches, 20,000 tons; apricots, 15,000 tons; pears, 3,000 tons; figs, 9,200 tons, and apples, 6,250 tons.

After the careful sortage of the apples from the Hood River and other regions on the Pacific slope, for case shipment, it would be

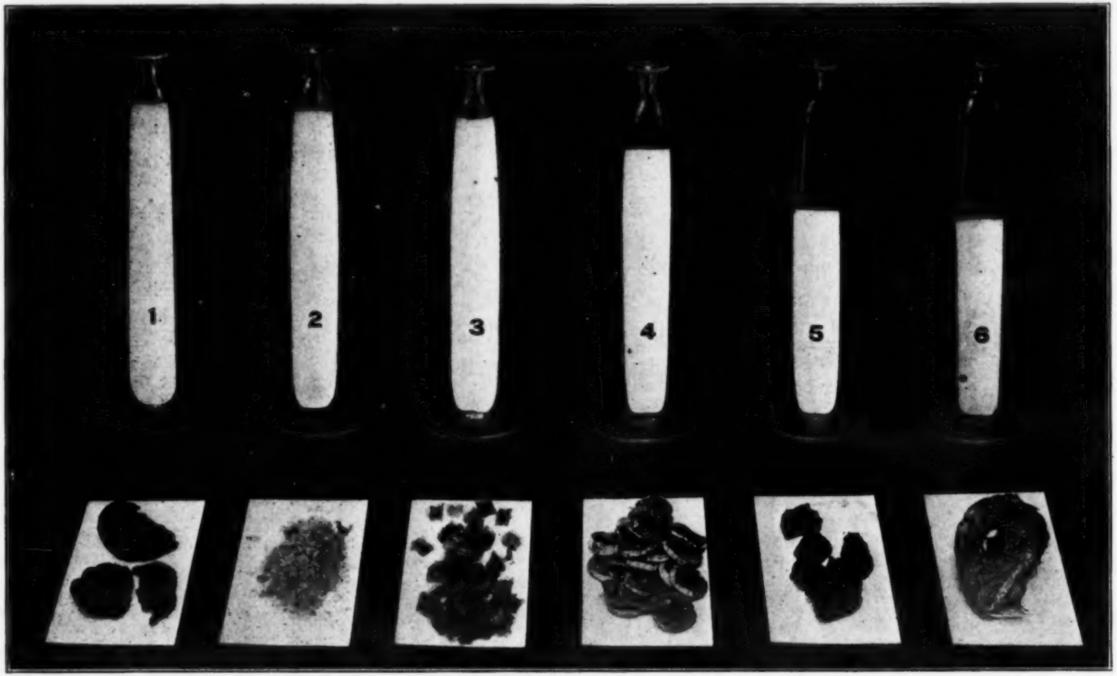


FIG. 2. ILLUSTRATION OF PROPORTION OF SOLID FOOD MATERIAL AND WATER IN VARIOUS ARTICLES OF DIET.

	Dry Solids	Water Extracted
(1) Tomatoes,	7 grains	75 cu. centimeters
(2) White of egg,	8 "	72 " "
(3) Potatoes,	21 "	65 " "
(4) Banana,	21 "	63 " "
(5) Beef,	24 "	60 " "
(6) Salmon,	30 "	55 "

interesting to know whether there is any salvage of the culls in the line of dehydration, or even in the cider vinegar line. The saving of culls in the orange groves is being carried out with great care and prices for this formerly waste by-product have mounted very markedly of late. They are generally marketed as marmalades.

The present meat products establishments under the packers trust complain that there is difficulty in disposing of the cheaper cuts, particularly of beef. This is really an indictment of the American extravagant method of living but with a vacuum outfit this will be overcome and the meat could be placed in the chamber with the animal heat still in the flesh and in best possible condition for a perfect output. It is also a medical question whether salted and smoked food as at present consumed are desirable in the ordinary dietary, but the palate has been habituated to their use and the purveyor faces a loss in its discontinuance. The vacuum device comes in as a stop loss and opens the door for a larger use of the cheaper and healthier fresh meat diet.

With fish this is even more to the point. This reaches the kitchen in one of three forms; as fresh fish in a restricted territory near the sea coast, as frozen fish at greater distance, but with a marked deterioration in quality, or as the cured fish, which is more of an appetizer and a thirst provoker than a sustaining article of diet. There is a great reservoir of food in the open sea and it is procured at a minimum of cost and is replaced by no other form of sustainance. The entire vacuum outfit can be carried and worked on a trawler with a great saving of space and without the uncertainty of profit which is now too great a factor in this line. There are many varieties of fish, not now utilized, which could be added to our bills of fare. In this group may be mentioned, shark, porpoise and whale.

There has already been gathered a fund of experience through which it is possible to answer many, if not all, the questions of the prospective investor. The fuel cost of the newest process is much less than by that using a current of hot air and is in the position to compete even with the sun drying process. In this latter case if there comes a succession of rainy, sunless days with tons of fish on the racks, after salting, there may be a total loss. The Norwegian fishermen who send down a steady outpour of salt fish for trade with Spanish consumers complain bitterly of this uncertainty. General costs, of course, will vary with the locality and the cost of fuel and labor, but with coal at $8 per ton and with labor at $4 per day the cost ought to run from ½ to 1 ct. per lb. of the material to be dried. The preparation is the same in the new as for the older processes, but three men per shift ought to handle the plant of three large units with an approximate capacity of 9 tons per 24 hours. Heavy motor trucks laden with an outfit provide a mobile establishment which could put in a profitable season extending almost through the entire year. An itinerary from the Gulf to the Lakes could be taken, with every day a working day. Smaller autos as collectors

would be a part of the outfit and the growers would be found more than willing to make planting contracts provided they were sure of a cash home market instead of the hazy commission trade as at present.

It must not be supposed that even the simple vacuum apparatus does not call for at least a fair degree of skill, or rather let us say, of watchfulness. The device is as near fool proof as possible, but it does demand honest, faithful care, after the preparatory operations. There are a few essential precautions. For instance, the dried material is very attractive to ordinary household pests, but a mouse-proof moth-proof storage room can be readily provided. Otherwise it will be occasionally found that some watchful mother-moth has planted a dose of eggs in a very choice position. The use of paper cartons with waxed lining, made air proof, will check any tendency to contamination and everything that Dame Nature has put in the plant, calories, hormones, and flavor will be passed on to the consumer.

Some of the trade figures in the ordinary course of the food industry today rise to gigantic totals. In the canned trade a recent compilation gives the yearly output of tomatoes at 361,000,000 cans, of corn at 259,000,000; of peas, at 236,000,000; of apples, apricots, peaches and pears, a total of 161,000,000; of squash and pumpkin, 25,000,000; of cabbage and kraut, 35,000,000; of beets, 17,000,000; of spinach, 58,000,000. Each can of the billion and a quarter total uses from 5 to 7 oz. of tin plate that soon find its way to the junk pile. Taking into the calculation the other charges which pile up in the figuring, it is little wonder that congested railroads, delays and damage claims are found in increasing volume. Yet the great association of canners with its thousands of members complain that but 15 per cent of the population are consumers of this class of edibles, and a gigantic program of advertising involving an outlay of millions of dollars is now under way to exploit and stabilize the industry. In this endeavor they have arranged to place an endorsement in the shape of a special mark on each can of the output of those canneries where the methods of manufacture are carried on in a way to warrant an approval of the contents of the can. In this way the association as a whole vouches for quality and it will be possible to put the careless manufacturers in a class by themselves, and exert a measure of discipline which will benefit alike the trade and the outside public.

From a commercial point of view there is yet much to learn on the whole problem of inducing the public to take up the dehydrated material. It is frequently an unknown product to the majority of users and there is a widespread and perhaps natural prejudice against it. There are no kitchen books making a specialty of dehydrated cooking and the simple requirements that the stuff be soaked in plain water before cooking is exaggerated into an irksome task. There is a wide field for its use in the great restaurants and hotels, but

even here, although the proprietors of the most expensively select hotels in the larger cities have already written their approval to the manufacturers, these same managers are careful not to blazon forth the fact on their menus before their patrons. One maker in Washington, D. C., made a special effort, introduced these goods into the kitchen of every cabinet lady and let that fact be known, but it did not appear that there was any increased popular demand. There is an opening for an up-to-date advertising expert to break the ice in letting the American public know of the great opportunity at its command. With such a lieutenant at his side, the way seems open to success on the part of a well equipped investor, whenever he may enter the field.

In the rivalry of nations in the open field of commerce this matter of dehydration comes forward very prominently. It was a general wonder how the English plan of starving Germany into submission when the blockade was established came to naught. The Teuton scientists simply pushed the dehydration of the lowly potato to the limit and the Empire from a total of 39 drying plants in 1906 ran the figures up over several thousand fold in the last year of the war; in addition, the 2,000 breweries of Germany were put at work on this phase of the food problem, and they kept the army and the population abundantly supplied. Even now these drying plants are turning out the desiccated product in such volume that a corps of selling agents covers the earth and in recent bidding for contracts in New York City, they went far below the figures submitted by the sellers of home products.

The commissary departments of the several armies in the field can throw a flood of light on the whole problem from their experiences in the past five years. With them it was water, water everywhere and all of it carried hither and thither at tremendous expense and to the exclusion often of fighting material of pressing importance. When a case of canned goods costing $2.60 in California is laid down at Havre at a cost of $7 and all to get an essential of less than 6 per cent nutritive components it brings out with spotlight distinction just what an inefficient system we are living under.

When it comes to an output that is always in demand the fresh fish drying industry is very inviting. There is at present a rising industry in the tanning of fish skin leather under the watchful eye of the U. S. Fisheries Department. The supply of raw material is inexhaustible and the labor of getting it is very cheaply paid. At present a few hundred thousand cans of the shark meat are placed on the market camouflaged as gray fish. This rechristening is a concession to the prejudice of the purchaser. These marine marauders have a fine muscular equipment and great slabs of boneless, fiberless, and highly nutritious meat can be carved off for the dehydrator. At present the leather people regard it as a waste by-product, and send it to the fertilizer vat from whence after drying it goes for manure or stockfeed. It is calculated that a thousand sharks per day are taken and at a low estimate of 50 lb. per animal,

tons upon tons of choice product are thus diverted with corresponding loss in food and cash. Already a group of Japanese investors are looking into the plan for starting in this industry. They already know the merits of fish food which is a standard article of diet with the Japanese of the Pacific Coast and their general extension of the industry is quite in course.

Another field where the way seems clear to the scoring of a profitable success is in connection with the banana industry. The plant has a way of making its bunches of fruit either extra large or very small and as only the average sized bunch will fit into the routine of commercial shipment, where the ripening is done during the trip from the tropics to the consumer, the fruit corporations have at present a by-product loss on their hands. The vacuum dryer gives out from this discard a product which at once is a delight to the eye and the palate; this can be prepared at the plantation with a minimum of expense and with the cheapest of labor and there is absolutely no factor of waste to be added onto the price of the marketed luxury. This extra may come in the shape of banana flour for the skilled housewife or in greater bulk may go to the big biscuit companies here and abroad and thus enable them to add to their list a delicious specialty. For years this saving has been the dream of the banana investor and it looks as though it were very close at hand. In confectionery too, various uses are made of the partially dried banana and in quantity a side line in alcohol seems inviting. For a time there were prospects of a blight on this industry in a new disease which was spreading through the plants, but, thanks to American horticultural skill, this trouble is about to end, and by selecting the correct variety for the location, the outlook has been much improved. Abroad, banana flour is much better known than here and in the French military hospitals large quantities are called for as a specially nourishing article of diet.

There are several lines which seem to offer at present attractive opportunities for export. Take the sweet potato and its sweeter confrére the yam. The state of Georgia has an ideal soil for its growth with an output of from 100 to 400 bu. per acre and with the frostless chance of a double crop of Irish potatoes followed by sweets. A permanent plant can be kept continuously employed in turning out a very profitable product and this too from a crop which it is otherwise difficult to completely utilize. The dry product is of a cornmeal type and has a variety of uses because of its large sugar content, which adapts it for cakes, for cookies and for pies as well. It ought to be very popular near its point of production. It is a crop which calls for a very cheap class of labor. A number of other uses would suggest themselves to any Southern agriculturist. It would be worth while in this connection to study the possibilities of Haiti—that richest bit of agricultural land on the earth—as a source of supply. It also has the cheapest of labor. As a sideline the making of a table syrup from sweet potatoes has been worked sufficiently to assure a profitable return from this specialty alone.

In any consideration of the commercial outlook in dehydration it should be borne in mind that foreign competition will play a large part. The new vacuum method is protected by patent laws abroad as well as at home and while American broad acres may be in our favor the higher wage demand of labor here may more than offset it. Certain it is that already the cost of the raw material is far lower on the continent of Europe than in the United States. A stabilized Russia might be a big producer but just now this is out of the question. The current reports from the Netherlands tell of cooperative efforts by the planters of potatoes where, against the price of about $10 a bbl. here, the Dutch have the tuber delivered at the mill door at 34 ct. per hectoliter of about 2¾ bu. The output is turned at

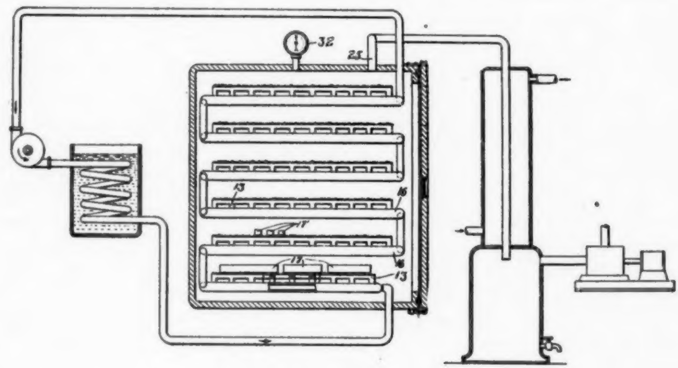


FIG. 3. OUTLINE SKETCH OF VACUUM DRYING APPARATUS SHOWN IN FIG. 1.

once into potato flour and for this there is a local demand far beyond the supply. It would seem that there is an opening for a great export trade from this side but here again we have to compare the large acreage yield under the intensive methods of the Dutch-German farmer and the extravagant, and often slovenly methods of the American agriculturist which gives a much lower acreage yield.

Possibly an opening may be found for a number of tropical fruits which now get into the northern markets at irregular intervals and not always in prime condition. This might be taken up as a side line by concerns carrying on establishments for the manufacture of fruit products, such as jellies, jams, preserves, etc. These would include Karo, Roselle fruits, Papayians, Mangoes and Pineapple.

The dried egg department has a story all its own. This takes us at once to China. The Orient was overrun by German agents before the war and they soon sized up the Chinese hen as an industrious little fowl laying little eggs but in great quantity which it was soon found had great possibilities. The Chinaman simply separated

the yolks from the whites and by the simple spray process in a current of hot air such as is employed in the making of powdered milk, the white albumen came out in sharp crystalline form while the yolks fell in a yellow powder. Under the pressure of the predominant German influence every pound found its way to Germany and was consumed there. When war drove the Germans out of China the egg driers seeking for a new outlet for the first time divulged the German-Chinese compact and now the product is pouring into all the entente lands in increasing volume. It is most surprisingly cheap; for instance, a pound of the powder ready for the baker for making up meringue and other similar delicacies for which the American demand is insatiable costs about $1 in this country. To make it up consumes about 12 doz. eggs of the diminutive Chinese type. Chinese cheap labor does the rest and fixes the price. It might take 8 doz. of our ordinary eggs to produce the same quantity but of course at American prices their use is out of the question.

The dried product in family and restaurant use may be made up in omelette and scrambled form and the bakers, large and small, are rapidly increasing its use. The old stories of *spots and rots,* meaning off color eggs which once came in great cans, are a matter of the past. These have a place in many industrial uses to which the wonderful complex egg is put in the tanning and other arts but a most vigorous custom house inspection protects the American stomach to the utmost and competition at the point of production keeps the price at its current low level. Of course the menus don't feature the use of these dried eggs, but they are coming in by the million and in rapidly increasing volume. Like all other dehydrated products they are absolutely without adulteration.

DISCUSSION

FRED. R. STILL: The remarks made by the author of the paper confirm what was stated in a paper presented by me in Chicago—that it is going to be a matter of dire necessity owing to a great scarcity of food or inability to get it, that will bring dehydrated food to that point where the people will be willing to accept it. Until that time arrives they will not use it. I agree with all that the author says. The Department of Agriculture has expended a great deal of effort trying to interest the public in dehydration, without much effect. Unless something is done very soon to get the farmers back onto the farms, I fear we will all have to become farmers or there will be nothing left to dehydrate.

A. M. LANE (written): It has been said in various quarters, that dehydrating fruits and vegetables will not become popular because it apparently destroys taste due to the process of drying. It has also been suggested that this method of drying is the result of a scientific investigation on the part of the heating and ventilating engineers, and they have failed to bring about a condition in the regulation of temperature and the condition of air to permit of a perfect dehydrated food. Assuming that the air is brought into the tunnel where the vegetables are dried, properly cleaned, and the temperature of that air is maintained uniformly, then, from a heating engineer's point of view, there should be no difference between a dehydrated vegetable and an air-dried, or sun-dried, vegetable. If there is any difference in the taste or the quality of the food, it is due to other influences over which, in my opinion, the heating engineer has no control. I have reached this conclusion after visiting several plants in Oregon and British Vancouver. The general practice heretofore has been to dry the vegetables on a wooden frame tray. The bottom of the tray is usually made of heavy galvanized wire cloth, but the frame has been made of wood. The operations are substantially as follows:

First the tray is washed in medium hot water and soda. Then it is rinsed in lukewarm water, and afterwards in cold water. Then the food to be dried is placed on the tray, and the tray set in a truck. From there it is moved into a compartment filled with steam, and remains there for approximately 30 to 45 minutes. Then it is put into a tunnel, having a temperature varying from 140 to 160 deg. depending on the kind of material to be dried. There is usually an air movement in the tunnel ranging from 600 to 1600 ft. a min.

As the moisture is evaporated from the food, the moisture in the wooden tray frames is also evaporated. The food within approximately 2 in., or probably 1½ in., of the wooden frame, absorbs some of this moisture, because the moisture in the food is evaporated before all the moisture in the wooden tray is evaporated, so that the food absorbs some of this moisture, and by so doing, takes on a sort of a woody taste. In other words, it is contaminated.

Now when this food is taken from the tray, the part that has been infected, it might be said, with the woody taste, is mixed with the balance of the food in the center of the tray, resulting in the whole lot having more or less of a woody taste, just the same as a little salt has the effect of giving a freezer of ice cream a salty taste. This condition has been absolutely eliminated by the use of highly enameled, japanned metal frame trays.

The next defect in the process of dehydrating is the kind of containers which are usually used for shipment. It seems to be the practice to pack the vegetables and fruit in cardboard containers, which are affected more or less by moisture or humidity in the places where they are finally stored, either in the basement of the ultimate consumer or in the warehouse of the wholesalers. Mildew, or mouldiness, take place very rapidly, or there seems to be considerable activity on the part of vermin. This is especially true of fruit which does not become very hard and brittle as a result of dehydration, such as apricots, prunes, peaches, etc. My recommendation would be that dehydrated food should be packed first in an oily paper, and then in a carton, or in a metal container.

I believe that if the heating engineers who are interested in dehydration will get acquainted with these facts, they will be in a position to defend themselves if they should ever have an occasion to dispute the claims of the producers of dehydrated foods that the heating engineer is responsible for dehydrated foods and vegetables not becoming popular. It is purely a matter of management and mechanical equipment, and not a matter of heating and ventilating, in my opinion.

No. 579

INDUSTRIAL ELECTRIC HEATING

By Wirt S. Scott[1], East Pittsburgh, Pa.

Non-Member

INDUSTRIAL electric heating is coming into prominence and general use, not because electric heat is cheaper than other forms of heating in a comparison of the power or fuel bills, for such seldom will be found to be the case, but because results have been obtained that heretofore have been unattainable by any other form of heating, all of which are contributing factors in reducing the cost of the completed product, reducing the amount of labor required, increasing the output, producing a better and uniform quality product and incidentally securing the ease and safety of operation characteristic of electric power.

Electrification of baking and drying ovens has come into general use, and in one industry, namely that of the manufacture of automobiles, including many of its allied branches, the adoption of electric heat has been universal; it is seldom that a gas oven is now seen in operation in such plants. Not all automobile companies, to be sure, have discarded their gas ovens, but most of those who still operate them, do so with the realization that they are actually penalizing themselves. Due to local conditions such as shortage of electric power or because of prospective building plans, they are not in a position to install electric ovens at the present time.

What are the reasons for changing from gas to electric heat? Would an industry, such as the automobile industry, adopt such a form of heating for practically all oven work unless those responsible were fully convinced that the expenditure justified the results? The automobile industry, our newest industry, started with such apparatus as was available at that time, but it was not tied down by any traditional ideas. As soon as a new method for securing certain results appeared by means of which a saving could be made, whether that saving meant labor, time, floor space, or whether it meant better quality of product, the automobile industry did not hesitate to give it a trial; if it proved successful, the apparatus, machine or whatever it might be was adopted and came into gen-

[1] Manager Industrial Heating Section, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, St. Louis, Mo., May, 1920.

eral use. It must be admitted that the automobile industry employs efficiency experts and engineers of the highest type; there is no other industry in which the cost of every operation performed or every part involved in the construction of its product is so accurately known. I wish to emphasize this, since the statements which follow are borne out by facts, and substantiated by the adoption of electric heat by this industry.

In the baking of enamel or japan on any metal, the work is dipped in or sprayed with enamel, allowed to drip for a period in the air and then baked in an oven. The enamel, which is of an asphaltum base, is mixed with linseed oil. A solvent consisting of a naphtha is added as a reducing agent or thinner, and must be completely distilled and driven out of the enamel coating before the oil begins to oxidize. It is the oxidation of the oil that forms the high gloss on automobile fenders, typewriters, etc. The naphtha vapors driven off the enamel are very volatile, and it is essential that the ventilation of the oven be sufficient at all times to keep the vapors reduced to a lean mixture. With a properly ventilated oven, it is impossible to obtain an explosion, regardless of the temperature of the heating medium, while under restricted ventilation, explosions were obtained on many samples of enamels at the baking temperatures of the enamels, at which time the heaters had been cut off for several minutes before obtaining the explosion.

In the electric heating of ovens, a ribbon type heater is used. A standard oven heater is one 21 in. long, 6 in. deep and 10 in. high, which has a rating of 2.5 kw. at 110 volts. For 220 volt circuits, two heaters may be connected in series. Four heaters are connected in series across a 440 volt circuit. As many multiples of these groups as may be required are placed in the oven. The heaters described are so constructed that they can be placed in any position without effecting their operation. In the heating of ovens, it is essential that the heat be generated at the proper place in order to secure the best results. In order to take advantage of the fact that heat rises, if left to its own air currents, it is necessary to place the heaters on the floor or as near the floor as possible.

Electric heaters may be placed along the side walls of the oven or on the floor at exactly the right point, and in sufficient quantity to produce the temperature required. If it is found that the first trial does not give uniform heating, the heaters can be moved very readily form one part of the oven to the other. The ease with which the heaters can be installed, and the individual units moved if necessary, is of considerable importance in obtaining uniform baking conditions. In box type ovens, as a rule, there is a tendency for the front part of the oven to be at a lower temperature than the rear, due to air leakage around the door, and from increased radiation losses through the iron work of the door. This condition is overcome by banking the heaters near the door, and putting a less number in the rear of the oven. In conveyor type ovens, the heaters may be distri-

buted so as to secure a gradual rise in temperature as the work progresses through the oven, finally entering the baking chamber where the temperature remains constant for a period of travel.

The ventilating of ovens is one of the most important considerations in laying out a heating system. Before the adoption of electric heat, ovens were ventilated from the ceiling. With electric heat, the oven can be ventilated from the floor line instead of the ceiling, sweeping out of the oven the volatile vapors from the naphtha as they are generated, and at the same time causing the hot air at the

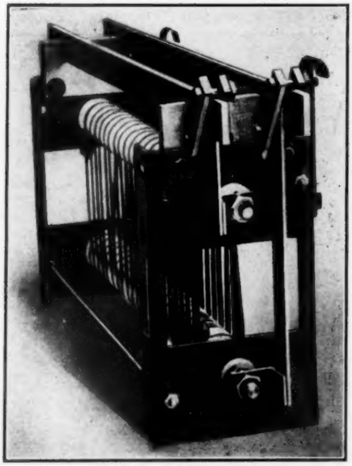


FIG. 1. HEATER FULLY EQUIPPED WITH STANDARD ACCESSORIES

Bus Bars are Screened Preventing Injury to Workmen and Mechanical Injury to Heater.

ceiling to flow downward, thereby getting the heat down to the part of the oven which tends to be the coolest. This method of ventilating produces a more uniform temperature throughout the oven, effects greater economy due to the ventilating being done at the coolest and not the hottest point of the oven, and insures safe operation as the highly explosive gases, being heavier than air, descend to the floor and are drawn off before a sufficient amount collects to do any damage.

With gas fuel, the gas is forced into the oven under pressure. A large volume of air is necessary to supply the oxygen required for the combustion of the gas. These burned gases, while they are of value as a heating medium in driving off the solvent, are of no value as an oxidizing agent, hence more air is required for that purpose. It is impossible to keep an oven absolutely clean inside, and the rapid

circulation of air through the oven causes small particles of dust to be picked up, swirled about the oven, and often deposited on the work. The products of combustion from the gas are constantly bathing the work, which also greatly impairs the quality of product. A small speck almost too small for the naked eye to see, will become magnified many times by being coated with enamel.

Blowing the air into an oven causes too great a velocity of the air at the points where the air enters the oven, followed by the dislocation of particles of dust. With electric heat, the ventilating system may be designed with reference to the results desired, since

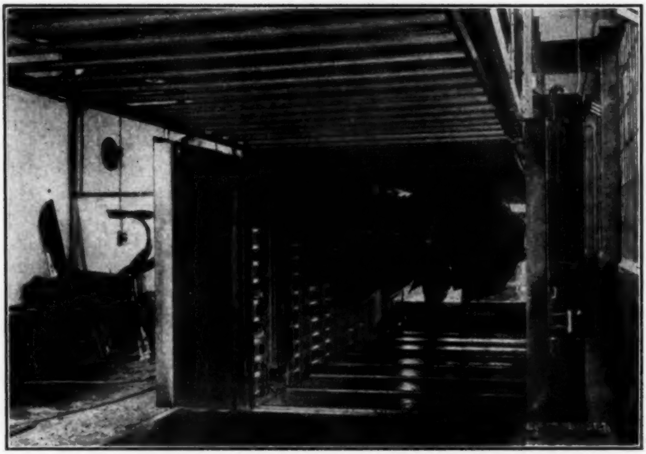


FIG. 2. SEMI-CONTINUOUS CONVEYOR TYPE OVEN.

Note the Heaters Banked Near the Doors and the Vent Pipe Extending Down Almost to the Floor.

there are no limitations placed on it by the use of electric heaters. Exhausters are used withdrawing the volatile gas and smoke at a point near the floor line.

In almost every case, by the use of electric heat, the baking period has been cut down to one-half or one-third of the time formerly required. This is due to the ability to locate the heaters at the points best suited for heating, maintaining uniform temperature in the oven, reduction of losses by excessive ventilation, and due to the fact that electric heat is a dry heat, there being no moisture-forming products of combustion generated in electrically heated ovens. By the reduction in the baking period, floor space has been saved, the extent of which is directly proportional to the decrease in time required for baking. This is of tremendous importance, as every square foot of floor space saved, reduces the investment by that

amount or releases valuable floor space for other manufacturing purposes.

The saving in labor is due primarily to two features—continuous conveyor type ovens and automatic temperature control. Continuous conveyor type ovens consists of a moving conveyor on which the work is hung, the conveyor moving at a fixed speed through the oven. That heat must be generated at a progressively increasing rate, so that the work will be pre-heated slowly until the maximum baking temperature is reached, held at the baking temperature for a short time, and then cooled off as it comes out of the oven. In

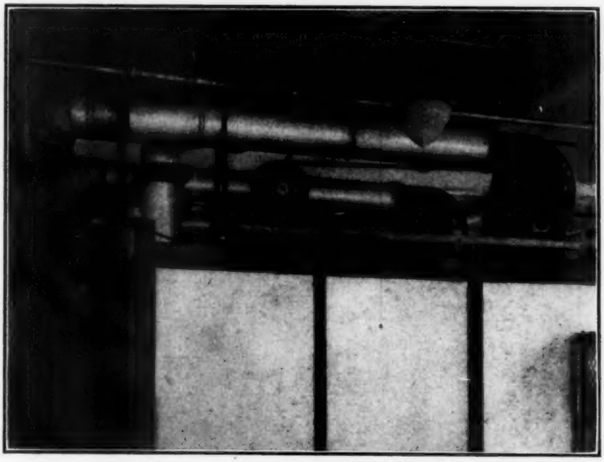


FIG. 3. VENTILATING SYSTEM USED IN CONNECTION WITH LITHOGRAPHING OVEN.

Eighty Per Cent of the Air is Recirculated in these Ovens.

connection with this process, large systems are now being installed for three coat work in which the parts to be enameled are hung on a conveyor, the conveyor descending over a dip tank of enamel; the work being automatically dipped into the enamel, continuing out and upward, then through the first oven, again dipping down into the second dip tank, through the second oven and so on, giving the work two, three or four coats as desired, according to the number of ovens used. There are numerous small conveyor-type ovens in operation which are equally effective in labor saving. In one plant when an oven is used for baking typewriters parts, four men are doing work which formerly required nine men.

Automatic temperature control is the most important feature of the entire electric oven system. By means of this control, the oven is placed in operation by the pressing of a button, after which the oven

will come up to the temperature desired and remain at that temperature indefinitely, continuously and entirely automatically, until the stop button is pushed at the end of the operating period. In most installations it is desirable, and in fact, essential, that the temperature of the oven be held constant, continuously and entirely automatically throughout the working day. The accomplishment of this feature

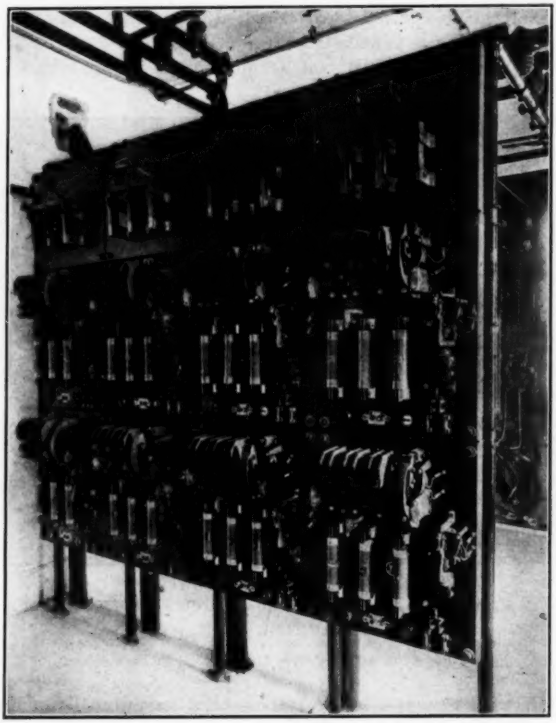


FIG. 4. A CONTROL PANEL FOR THE OPERATION OF A GROUP OF FOUR SEMI-CONTINUOUS CONVEYOR OVENS

necessitates the use of the thermostat, with suitable relays, to be used in connection with the magnet switches. The thermostat consists of a contact making instrument, the movable element being actuated by pressure generated in a capillary tube that extends into the oven. The tube is filled with gas, vapor, or mercury. The pressure generated in the tube and exerted on the movable hand is a function of the temperature; hence the instrument may indicate temperature by being so calibrated and the scale marked accordingly. Adjustable contacts or indicators are provided, by means of which the temperature may be held constant between the operating limits desired.

A relay is required in connection with the thermostat for operating the main magnet switches. This relay consists of a single-pole magnet switch with an additional interlock or secondary switch.

Assume that the oven is cold, and it is desired to heat it and keep it in continuous operation. The adjustable contacts are set for the maximum and minimum allowable temperature and the push button closed. Instantly the current flows through the low contact, the movable pointer and through the relay coil. Energizing the relay coil causes the relay switch and interlock to close simultaneously. The closing of the relay switch causes the main magnet switch coil to be energized, closing the main circuit. Closing the interlock gives a new path for the current to the relay coil, so that when the movable hand breaks contact with the low contact it does not break the circuit. The temperature of the oven increases until the movable hand reaches the high contact, at which instant the relay coil is shunted, causing it to be demagnetized, and opening the relay switch

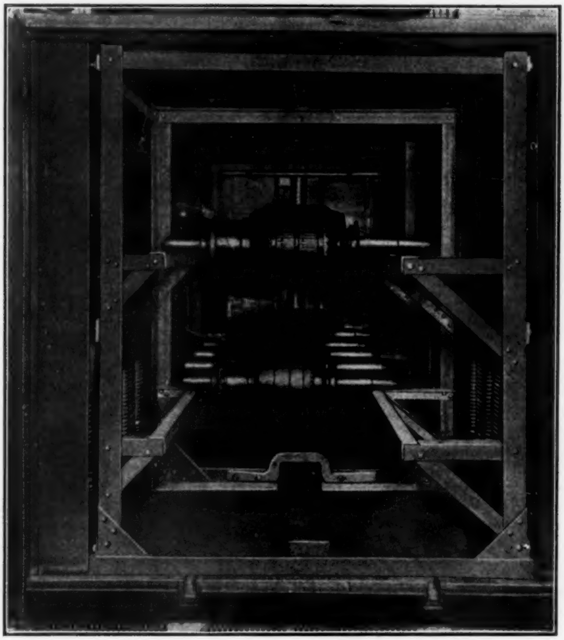


FIG. 5. ARMATURE BAKING OVEN.

The Air is Removed From the Bottom of the Oven, Part Exhausted to the Atmosphere and the Balance Returned at the Top of Oven. An Exhauster Gives the Desired Amount of Ventilation.

and consequently the main switch. As soon as the heat is cut off the movable hand begins to travel from the high to the low temperature contact and, upon reaching the lowest temperature setting or limit, contact is again made, energizing the relay and again closing the main switch. This operation will go on indefinitely.

It is rapidly becoming the practice to install individual exhaust fans in connection with each oven for the purpose of insuring proper ventilating conditions. When natural ventilation afforded by the use of a high stack is depended upon, the ventilation is not a constant quantity, but varies from day to day depending upon humidity, air temperature, and wind. Even with an exhauster, the ventilation will become impaired in course of time due to the heavy oily vapors con-

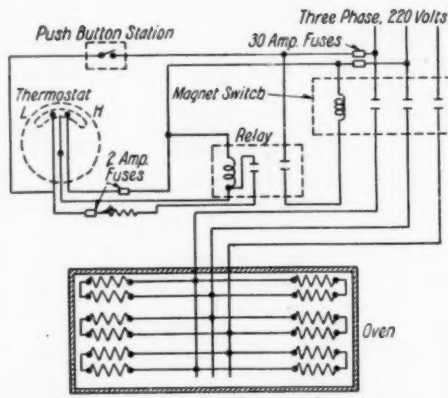


FIG. 6. DIAGRAM OF CONNECTIONS OF AUTOMATICALLY CONTROLLED, ELECTRICALLY HEATED OVEN ON THREE-PHASE 220-VOLT CIRCUIT

densing in the vent pipes, forming a tarry substance which finally solidifies and cakes. Thus the vent pipes gradually become restricted as to the cross sectional area, with the possibility that in course of time the ventilation will become sufficiently impaired to prevent the escape of the volatile naphtha vapor and an explosive mixture is formed. The arrangement just outlined is designed to overcome this condition by using a motor operated exhauster. In the first place, the power for operating the main magnet switch is taken from the exhauster motor circuit and connected back of the starting switch, thereby eliminating the possibility of the oven being operated without the exhauster. In the second place, it is known that the power required to operate an exhauster or blower varies with the amount of air passing through it. While in this case the power would not vary directly with the amount of air handled, the variation is sufficient to enable an instrument to be calibrated in such a manner as to give a close indication, by the decrease in current input to the

motor, of the extent to which the vent pipe has become stopped up. Further, if a relay be inserted in the motor circuit as shown, with a suitable coil and short circuiting plunger, the stopping up of the vent pipe, whether caused by the vapor condensing in the pipe, accidental closing of the damper, or a piece of work falling off the conveyor across the vent opening, will be followed by a decreased input to the motor. This decreases the current flowing in the current coil to such an extent that the magnet no longer has sufficient power to hold up the plunger and weight, and allows it to drop,

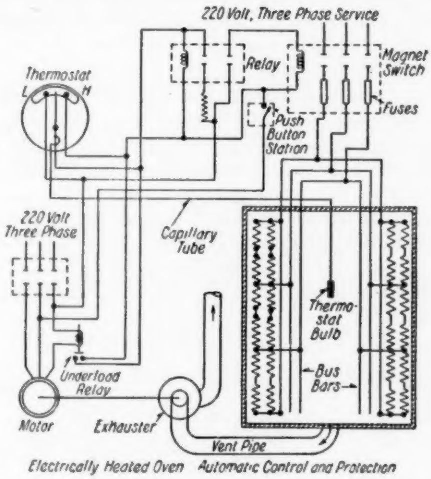


FIG. 7. DIAGRAM OF CONNECTIONS OF AUTOMATICALLY CONTROLLED AND VENTILATED ELECTRICALLY HEATED OVEN ON THREE-PHASE 220-VOLT CIRCUIT

short-circuiting the two auxiliary contacts which in turn short-circuit the thermostat relay coil, and cause the main magnet switch to open. Thus, with a properly equipped electric oven, the danger from explosions of volatile gas may be entirely removed.

The advantages to be derived in the use of electric heat depends upon the specific applications. As a summary, the following advantages are listed, one or more of which will apply to almost any installation, and make the installation of electric heat a paying investment:

1. Electric heat is clean.
2. There are no objectionable gases to vitiate the air.
3. There are no products of combustion to collect on the work.
4. Elimination of the fire hazard.
5. Ease of operation.

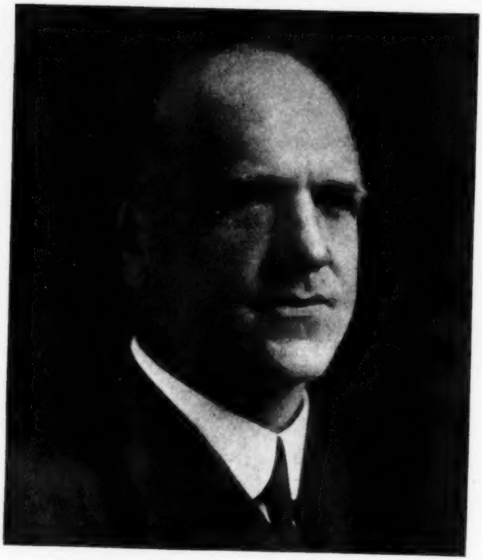
6. Heat may be applied in the most economical and direct manner.
7. A definite rate of heating may be established, and these results reproduced in successive operations.
8. The temperature may be automatically maintained at the desired operating point.

Electric heating permits of making experiments to determine the best method of applying heat, the proper rate of heating and the maximum temperature permissible for obtaining the best results. And once these factors have been determined an operator is enabled to reproduce these results day after day with the least amount of labor and attention.

Electricity has not been used to any extent in the heating of buildings, but it is but a question of time until this will be done on a large scale. Many plants have surplus power, particularly those located on or near waterfalls, such as in the northern part of the U. S. and Canada, where coal is very expensive. In such cases it would be far cheaper for such plants to install the necessary generating equipment and heat their buildings electrically than to burn coal and heat by means of steam. Heaters could be grouped in a housing, and air blown through them in exactly the same manner as now being done with steam coils.

In Memoriam

	Joined the Society	Died
ROY LIGE, Auburn, Ind.	July, 1915	Jan. 20, 1920
CHARLES B. MCQUILLEN, New York.	July, 1915	Jan. 28, 1920
JOHN A. BUSS, St. Louis, Mo.	Mar, 1920	Feb. 9, 1920
JOHN E. HENRY, Louisville, Ky.	June, 1916	Feb. 17, 1920
LEWIS A. LARSEN, Watertown, S. D.	Aug., 1918	Mar. 29, 1920
ELLSWORTH F. SCHOFIELD, Wheeling, W. Va.	Feb., 1917	Apr. 22, 1920
JOSEPH J. CARLOTTI, New York, N. Y.	Sept., 1919	May 23, 1920
ERNEST BROWN, Des Moines, Ia.	June, 1919	June 29, 1920
BERNARD GAUSE, Jacksonville, Ill.	Dec., 1904	July 19, 1920
WILL L. BRONAUGH, Evanston, Ill.	July, 1903	July 27, 1920
CHARLES W. NEWTON, Baltimore, Md.	Charter Member	Aug. 6, 1920
FRANCIS W. MCGUIRE, Rockford, Ill.	June, 1908	Sept. 23, 1920
JOHN R. ALLEN, Pittsburgh, Pa. (Past-President)	Dec., 1906	Oct. 26, 1920
JOHN A. MILLER, Cleveland, Ohio	June, 1916	Nov. 9, 1920
CHARLES S. BAVIER, New York, N. Y.	Oct., 1915	Nov, 27, 1920
HENRY HAMMELLE, Paris, France	Dec., 1901	1920
P. H. FABRICIUS, New York, N. Y.	June, 1912	1920
FRANK SHAY, Albany, N. Y.	Oct., 1915	1920



John R. Allen

July 23, 1869 - October 27, 1920

John R. Allen

NO one who was ever in contact with, or had an opportunity to appreciate the fertility of mind of Prof. John R. Allen, can hear his name mentioned without feeling the veneration and respect that is due him. The great shock of his sudden death after a short illness in which pneumonia developed, has called forth expressions of sympathy from his great host of friends all over the country. He was a man who combined the characteristics of the educator, the scientist, the consultant of the highest order on all matters pertaining to mechanical, and heating and ventilating engineering. He was a man among men and by reason of his democratic and charming personality, his ever keen sense of humor and ready wit, his innate and intuitive sense of fellowship which was the result of a life study of human nature, he made friends everywhere.

There was a sincerity and determination of purpose in his character which always stood out clearly and this makes his loss not only to his friends, but also to the engineering profession at large, seem a heavy one indeed. Nothing points out so unmistakably his wholehearted interest in the engineering profession and in advancing and furthering its growth, as his acceptance of the Directorship of the Research Bureau of the Society at Pittsburgh, Pa., at a material disadvantage to his personal welfare. There is no doubt that his standing among educators and the engineering industry in general and his unusual qualifications for a big work, entitled him to a far more lucrative position and in fact, he was often honored by very attractive opportunities, but he was always loyal to the Society and its program of research.

Professor Allen was not a dreamer; he was an intensely practical and capable engineer and scientist. If he could have been spared long enough to complete more of the valuable fundamental investigations in which he was engaged, the gain to the engineering profession would have been incalculable. As it is, however, the research data which he personally secured have been considerable and the work inaugurated and developed by him as Director of the Research Bureau, has proven capable of bringing out much more data that will be of inestimable value. He has left the Society a pleasing legacy in the splendid organization of the Research Bureau which he was able to establish on such a firm footing that its work may continue without interruption even though it lacks his direct supervision.

Professor Allen's intimate touch with the field and his wonderful knowledge of the art, enabled him to initiate the investigations of the Bureau along much needed lines. In addition, he gathered around him a working personnel and created such an atmosphere of interest and loyalty as to insure continuity of the work along lines planned. In fact, he had remarked only a short time before his death as to how happy he was to have been able to so establish his working organization, that he could now be absent from the Bureau without loss or delay in the work; he had planned considerable traveling with the thought of keeping in touch with the activities of the various research laboratories throughout the country.

John R. Allen was born in Milwaukee, Wis., on July 23, 1869. He obtained his preparatory education partly at the Milwaukee High School and partly at the High School in Ann Arbor, Mich. After this he entered the University of Michigan, where he received the degree of Bachelor of Science in 1892 and later, the degree of Master of Mechanical Engineering in 1896.

From 1892 to 1893, he served an apprenticeship at Bay City, Mich., with the Bay City Industrial Works, erecting machinery. After that he was for two years connected with the L. K. Comstock Construction Company at Chicago, Ill., and during the period from 1895 to 1896 he was a member of the firm of Ball & Allen.

In 1896 he was invited to the faculty of the University of Michigan, where he served in the various capacities of Instructor, Assistant Professor, Junior Professor, and then Professor of Mechanical Engineering in the Engineering Department up to the year 1911. At this time, he was called to Turkey to build up an Engineering Department in Robert College in Constantinople. He was made Dean of that Department and stayed there until it was thoroughly organized; during his sojourn in Turkey, he was on leave of absence from the University of Michigan. Two years after that, he headed an expedition into an unexplored region of Western Mexico to investigate peculiar trees in that region which promised a substitute for rubber. He was called upon for consulting work in all parts of the country during his long connection with the University of Michigan, and this Mexican expedition was only the forerunner of several other important expeditions, such as his expedition into the Rocky Mountains to report on water power projects, and several other engineering expeditions into Northern Michigan and Southern Canada.

From 1915 to 1917, Professor Allen was Head of the Mechanical Engineering Department at the University of Michigan. In 1917, he left the University of Michigan to accept the Deanship of the College of Engineering and Architecture at the University of Minnesota, and remained there until August 1, 1919, when he assumed active charge of the Research Bureau of our Society then just established at the Bureau of Mines Laboratory at Pittsburgh.

Professor Allen has been extremely active in Society work, having been President of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS in 1912, Past-President of the Michigan Chapter of the Society, Past-President of Minnesota Chapter of the Society,

and at the time of his death, President-Elect of Pittsburgh Chapter. He was also at this time Vice-President of *The American Society of Mechanical Engineers.* He was a Past-President of the *Michigan Engineering Society,* Honorary Member of the *National District Heating Association,* Past-President of the *Society for the Promotion of Engineering Education,* Member of the *British Institute of Heating and Ventilating Engineers,* and Member of the Honorary Societies, *Tau Beta Pi* and *Sigma Psi.*

He has been a contributor of important technical papers to both the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and *The American Society of Mechanical Engineers* and his papers have all proven to be reference works of great value. His books, entitled, Notes on Heating and Ventilation, published by Domestic Engineering, Chicago, Ill., and Heating and Ventilation, published by McGraw-Hill Book Co., New York, N. Y., are considered as standard text or reference works.

Professor Allen's death was caused by pneunomia which resulted from a slight cold that troubled him when he addressed the October meeting of Eastern Pennsylvania Chapter on the 14th. His address, at this meeting, promised a brilliant future for his work. He spent the 15th and 16th in New York, but on return to Pittsburgh on Sunday, the 17th, his cold developed into tonsilitis which confined him to his home all of the following week. There was no material improvement during that week and on Saturday his illness was pronounced pneumonia. Everything possible was done for him and not only was there a consultation of doctors, but also a prominent specialist on pneumonia was called in; these efforts were, however, of no avail and he died at 10 P.M. on Tuesday, October 26 at the age of 51 years.

Professor Allen is survived by a wife and a daughter residing in Pittsburgh, his daughter attending the Margaret Morrison School of the Carnegie Institute of Technology. Professor Allen also maintained a residence in Ann Arbor, where beautifully located in the outskirts, he had an attractive farm, and it was his great pleasure to spend much of his leisure time there.

The remains were interred in Forest Hills Cemetery at Ann Arbor, Mich. There were services at his Pittsburgh home on the evening of Wednesday, October 27. The body was taken to Ann Arbor on Thursday and the funeral was then held at the First Baptist Church there on Friday afternoon, October 29. Six of his former co-workers at the University of Michigan, Professors H. E. Riggs, H. C. Anderson, Emil Lorch, J. C. Parker, A. H. White, and H. C. Sadler, served as pallbearers.

His loss has proven a great blow to his multitude of friends and will be keenly felt, but his great work for the betterment of the engineering profession and his many accomplishments in developing original and dependable data have erected a monument to his memory that will live forever. It will create a standard for his followers in striving to follow in the paths he marked out toward the enlightenment and the betterment of the engineering profession.

Charles W. Newton

Charles W. Newton, of Baltimore, Md., an old and valued member of the Society, passed away on August 6, 1920, to the deep regret and sorrow of his friends and associates. Mr. Newton had attained the age of about 85 years. He was a charter member of the Society and in 1908, through the action of the Board of Governors, he was made an honorary member of the Society. This honor was conferred upon him, as the result of his many virtues as a man, in addition to his ability and wisdom as a heating and ventilating engineer. He was a man of experience and knowledge and was always ready to impart it to his fellow men. He was well versed in all problems connected with heating and ventilation, and was also identified with some of the most notable hot-water heating work installed in the United States.

Due to ill health, Mr. Newton retired from active work for several years prior to his death. He is survived by his wife. The Officers and members of the Society will feel deeply the loss of his keen interest in professional and engineering progress.

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